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COMING MEETINGS

WINTER CONVENTION, New York, N. Y., February 7-11

SUMMER CONVENTION, Detroit, Mich., June 20-24

PACIFIC COAST CONVENTION, Del Monte, Calif., September 13-16

REGIONAL MEETINGS

South West District No. 7, Kansas City, Mo., March 17-18

Middle Eastern District No. 2, Bethlehem, Pa., April 21-23

Northeastern District No. 1, Pittsfield, Mass., May 25-27

MEETINGS OF OTHER SOCIETIES

The American Physical Society, New York, Feb. 26; Washington, April 22-23

National Electric Light Association
Southwestern Division, New Orleans, La., April 26-29
Nebraska Section, Grand Island, Neb., April 27-28

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Vol. XLVI FEBRUARY, 1927 Number 2

TABLE OF CONTENTS

Papers, Discussions, Reports, Etc.

Institute and Related Activities

A REQUEST FOR CHANGE OF ADDRESS must be received at Institute headquarters at least ten days before the date of issue with which it is to take effect. Duplicate copies cannot be sent without charge to replace those issues undelivered through failure to send such advance notice. With your new address be sure to mention the old one, indicating also any change in business connections.

Current Electrical Articles Published by Other Societies

Institute of Radio Engineers, Proceedings, January 1927

Piezo-Electric Crystal-Controlled Transmitters, by H. Crossley

Simultaneous Production of a Fundamental and a Harmonic in a Tube Generator, by Hoy J. Walls

An Automatic Fading Recorder, by T. A. Smith and G. Rodwin

Behavior of Alkali Vapor Detector Tubes, by H. A. Brown and C. T. Knipp

National Electric Light Association Bulletin, January 1927

Industrial Electric Heat, by N. J. Roberts

The Farmer and the Electric Light and Power Companies, by R. F. Pack

Physical Research Methods in the Study of Dielectric Materials, by J. S. Lapp

Westinghouse Engineering Achievements for Electrical Industry in 1926, by H. W. Cope

Rural Electrification Studies in Idaho, Report by Idaho State Committee on the Relation of Electricity to Agriculture

Journal of the A. I. E. E.

Devoted to the advancement of the theory and practise of electrical engineering and the allied arts and sciences

Vol. XLVI FEBRUARY, 1927 Number 2

Relationship Between Physics and Electrical Engineering

The usual understanding of the relationship between electrophysics and electrical engineering is that physicists discover facts and laws, develop methods of measurement, determine various constants, propose and work out in detail mathematical theories and hypotheses, etc., while electrical engineers later apply some of these valuable facts and theories to the design, construction, and operation of various practical devices and aggregates. While such a relationship exists between the two professions in many cases, yet there are numerous other cases in which certain practical requirements have to be met empirically, ahead of a careful study by physicsts, or where physicists and engineers have been working in parallel on different phases of the same problem.

The question of the actual relationship of physics to electrical engineering is of interest not only to the student of the history of the art, but to the industrial manager as well. He should know the following facts: (1) that in many of the most important technical problems confronting his engineers, they can get no help from physicists, because the latter may still be struggling with simpler problems, because the particular problem did not happen to arouse the interest of a prominent physicist in the past, because the center of interest in physics at the time seems to lie in an entirely different domain, etc. (2) That the physicist is always at liberty to choose some simplified conditions, a particular range of factors, a material that suits him best, etc., while the engineer is usually much more limited in his choice. As a consequence, there may be an ample collection of data and a satisfactory theory, but which unfortunately do not cover the desired range, and the bridge between the two is not always readily spanned. (3) Much useful physical information is clothed in a highly advanced mathematical language which only few engineers can follow.

This state of affairs has led to the establishment of several research laboratories connected with large manufacturing and operating companies. In these laboratories, problems in pure physics and chemistry are correlated with proximate and distant practical problems. Moreover, a gradation is established in the personnel, whereby at least some of the achievements of a theoretical theoretician become useful to a practical practician. This is done by providing two intermediate grades, those of practical theoretician and theoretical practician. It is like a person who can speak English only communicating his thoughts to one who can speak French only, through two intermediaries, one of whom speaks English and German and the other who speaks German and French.

One of the purposes of the Electrophysics Committee of the Institute is to act as an intermediary between theoretical physicists and practising engineers; the present chairman believes this liaison to be its most important function. Within the last two or three decades, physics has made strides exceeding the achievements of the preceding several centuries, and it is of extreme importance to keep electrical engineers acquainted at least with the most salient new theories, methods, and facts in physics. Of course, some Institute members are also working on problems in applied physics, so that soliciting and reviewing papers from such members is also an important function of the Committee. Papers on networks, on magnetic topics, on dielectrics, on plotting of fields, thermionics, electric waves, etc., are being constantly submitted and frequently presented at Institute meetings. However, such papers may readily lead to inbreeding and to obsolete methods, unless fresh ideas are constantly pouring in from leading physicists.

In the past, the Institute management has given a limited amount of space to an influx of such ideas from physicists, both at its meetings and in its publications, and it is to be hoped that more space will be available in the future. With all the importance of the present problems and achievements in engineering, we must not lose sight of the problems of the future, whose first stage lies in a knowledge of the status of the corresponding basic physical facts and methods of analysis. To keep our younger members posted on and interested in such matters is our direct duty, lest the profession deteriorates in the future.

At the last Annual Meeting of the American Physical Society, in Philadelphia, December 28-30, the largest number of papers on a single topic related to the subject of spectroscopy, from the lowest infra-red to the hardest X-rays. While spectroscopy is of rather limited application in the present problems in electrical engineering, it may become an important tool in quite an unexpected field. Some of the most intimate knowledge of the structure of the atom has been obtained spectroscopically, by a study of its radiations. Some future practical problems based on the finer structure of matter, for example, some problems in magnetism, dielectrics, glowing vapors, ionization, etc., may require spectroscopic principles for their solution. The so-called quantum theory of energy, which is a basic foundation of the whole modern atomic physics, is also closely connected with spectroscopic analysis, and from now on, an engineer who is not familiar with the foundations of the quantum theory will be cut off from much of the future progress in physics, both theoretical and experimental.

X-rays and their use in the study of the structure of matter have also attracted some attention at the meeting. On the other hand, the interest in thermionics has subsided considerably, the problem apparently having been "sucked dry," at least for the present.

The remaining papers presented at the meeting seem to lie in scattered domains, there having been one or two read on the following subjects: photo-sensitivity, oscillographs, peizo-electricity, waves, contacts, solid dielectrics, electromagnetic forces, atmospheric electricity, radiometry, beta-rays, statistical mechanics, acoustics, vacuum gage, heat insulation, measurement of very short time intervals, mobility of ions, ionizing potentials, etc. This list will give some idea of the present problems in physics, although for a more accurate quantitative judgement one would have to tabulate papers presented at several meetings of physicists, in different countries, as well as articles in leading periodicals devoted to physics.[1]

An electrical engineer engaged in semi-theoretical work, especially on dielectrics, arcs, vacuum conduction, high-voltage phenomena, magnetic apparatus, radio, etc., cannot possibly expect to keep in touch with the progress of the underlying physical measurements and theories through the Institute publications alone. It will be increasingly necessary for him to be posted on the work of pure and applied American physicists,

1. For a general orientation, the reader is referred to the "Introduction to Contemporary Physics," by K. K. Darrow (Van Nostrand).

at least through their organ, *The Physical Review*.[2] The work of foreign physicists may be readily followed through *Science Abstracts, Sec. A*.[3]

During the Winter convention of the Institute, the committee on Electrophysics expects to have a meeting at which it is proposed to prepare a list of topics in electrophysics, of prime importance to electrical engineers. Such a list may be of value in directing their attention into definite channels. A list of possible authors of future papers will also be prepared, and with such an underlying program, the work of this committee, as well as that of its successors, should be much facilitated and systematized.

VLADIMIR KARAPETOFF, *Chairman*,
Committee on Electrophysics.

Some Leaders of the A. I. E. E.

HARRIS J. RYAN, thirty-sixth president of the Institute (1923-24) was born at Powell Valley, Pa., January 8, 1866. His early education was acquired at the Baltimore City College and the Lebanon Valley College. In 1883, when an electrical engineering course was first inaugurated at Cornell University he entered and was graduated in 1887. For two years thereafter, associated with J. G. White and D. C. Jackson, he carried on a general engineering practise under the firm name of Western Engineering Company, but in 1889 he returned to Cornell to take charge of the electrical machinery laboratory. This marked a real epoch in his career in a change from the commercial field to one of scientific research, although his interest in both has always remained broad in its application. It was also about this time that his most notable characteristic evidenced itself; the fine determination and almost inexhaustible patience so essential to the success of a research engineer. In reviewing his achievements, one cannot but be impressed with the clear foresight and unprejudiced manner in which he approached any problem confronting him. One series of experiments made by him resulted in his famous paper on transformers, presented before the 41st meeting of the Institute in 1889. A few years later, in joint authorship with M. E. Thompson, he produced the paper on methods of preventing armature reaction, the outgrowth of which was the Thompson-Ryan generator, forerunner of the present day interpole type used now almost universally in d-c. generators and motors. And of even greater value to industry has been his work with alternating current. When he undertook its investigation, the scientific world knew little concerning it and less regarding the field of high voltages. He started this work in the laboratory at Cornell, constructing under his own supervision, much of the equipment necessary to progress. It is interesting to know that the 90,000-volt dry insulated transformer then built still plays an important part in the laboratory's equipment. His advancement was rapid and in 1890 he was chosen assistant professor in Electrical Engineering. In 1895, when only 29 years of age, the "kid professor," as he was affectionately called, was honored with the appointment of professor in full charge of Electrical Engineering at the university. It was in 1897 that some experiments in the Rocky Mountain region gave birth to the announcement of a 40,000-volt limit for transmission lines. Professor Ryan felt that possibly all factors had not been given adequate consideration. His pioneer spirit was challenged and he began an intensive study of the situation. In 1904 he summarized the results of his investigation in his A. I. E. E. paper, *Conductivity of Atmospheres at High Voltages*, the fundamentals of which were a distinct contribution to science as were also data contained in his later paper before the Institute (1911)—*The Open Atmosphere and Dry Transformer Oil as High-Voltage Insulators.*

In 1905 Professor Ryan accepted a call to Stanford University, where he continued his research work as Head of the Electrical Engineering Department. In recognition of his effective work in higher voltages, the University built in 1913 a high-voltage laboratory, having as its principal equipment a 350,000-volt transformer. He immediately began the development of other types of equipment—one outstanding result an oscillator capable of producing a discharge 10 ft. long and of such intensity as to closely resemble real lightning. He also made a study of high-voltage effects at radio frequencies and cooperated with the Federal Telegraph Company in the design of a 100,000-volt insulator for large radio transmitting antennas. Subsequent developments of the Cathode Ray Oscillograph received much of stimulus from his work. In 1900 he began a series of studies with his objective the adaptation of the Braun type of Cathode Ray tube for engineering measurements. His first years resulted in a very satisfactory method of determining current and voltage wave forms which was later applied to power in a-c. circuits. This work commenced at Cornell led to the presentation of his two Institute papers *The Cathode Ray Alternating Current Wave Indicator* (1903) and the other on the *Cathode Ray Power Diagram Indicator* (1911). He has also given the subject a prominent place in several of his other papers. Of recent years he has devoted much of his time to the study of insulation and insulators for use on high-tension lines—a work of inestimable value to the profession. In recognition of his many contributions to the knowledge of power transmission, he was awarded the degree of Doctor of Laws by the University of California, March 23, 1925, and the same year he was Edison Medalist. Professor Ryan was Judge, Board of Awards at the World's Fair, Chicago, U. S. Government Delegate to the International Electrotechnical Congress, St. Louis, Member of the Jury Panama Pacific International Exposition, San Francisco and Director of the Supersonics Laboratory of the National Research Council, Pasadena, Calif., Consulting Engr. Los Angeles Aqueduct Power Bureau, Fellow of the American Ass'n. for the Advancement of Science, Member of the Am. Electrochemical Soc. Institute of Radio Engineers, Soc. for the Promotion of Engineering Education, Am. Phys. Society, Phi Kappa Psi, Sigma Xi. The new Harris J. Ryan High Tension Laboratory at Stanford University stands a fitting monument to the untiring energy and ability of the man whose name it bears.

History of Lighting Told in Light House Changes

Almost the whole history of lighting is told in the changes made in the first lighthouse built by the United States as an independent government. It's at Cape Henry, at the entrance of Chesapeake Bay.

When the United States finished the lighthouse it used fish oil. That was in 1792. Sperm oil was substituted in 1810. Our whale fisheries began to decline and other oils were sought, first rapeseed or colza oil and later lard oil.

Then we began to realize our wealth in petroleum, and kerosene was used. In 1910 a great improvement was made. Wick lamps were discarded and vaporized kerosene, with an incandescent mantle, was installed. But it lasted only a dozen years, when an electric incandescent lamp was substituted. There's a whole history of light production in 133 years—fish oil, whale oil, colza oil, lard oil, kerosene, gas, electricity.

2. Published in Minneapolis, Minn.; subscription price for non-members is ten dollars.

3. Subscription taken at the Institute headquarters at $5.00 per year for A. I. E. E. members.

Transverse Reaction in Synchronous Machines

BY J. F. H. DOUGLAS[1]

Associate, A. I. E. E.

Synopsis—The confusion existing at present in the theory of synchronous machines is shown to be due to insufficient experimental evidence of the behavior of this type of machine under transverse magnetizing (cross magnetizing) conditions. A method of testing which yields the needed data is described. The results of these tests on a particular machine are given and analyzed. It is proved, for the machine tested, that the effect of transverse reaction can be most accurately estimated by the use of a magnetomotive force diagram. Experimental constants useful in design are found. A theory of the operation of synchronous machines is proposed, and a diagram for finding the performance of a synchronous machine from experimental tests is given; which, it is hoped, will be more accurate than present methods.

* * * * *

Introduction

THE subject of the performance of synchronous machines seems to be of perennial interest. Many theories have been proposed with their appropriate methods of computation. Nearly every text-book is a monument to the confusion of this subject, a confusion resulting from an insufficiency of facts. It is interesting to note how theory has become more sound as experimental facts have become more extensive.

When the open and the short-circuit tests were the usual compromise tests, we had the e. m. f. and the m. m. f. methods which were based upon them, with the Torda-Heyman method as a compromise. When the shape of the full-load zero power-factor saturation curve became known, the improved Kapp diagram and the Potier diagram were developed. A number of discrepancies between observed and computed results, together with theoretical studies of the variation of air-gap permeance, have led to various proposals for the perfection of the theory of this machine. In the judgement of the writer, the best method derived to date is that of Andre Blondel[2], and the best exposition of this method that of Professor V. Karapetoff[3]. As expounded, it is chiefly a design method. Although it is possible to apply it to experimental data, the directions are not clear enough to enable it to be easily applied for this purpose. Some recent refinements in this method have been made by Karapetoff, and Doherty and Nickle[4].

The elimination of guarantees of regulation at other than zero power factor, has led to the attitude that present methods are good enough for practical purposes. There has been a gradually increasing number of facts, however, that indicate that further improvements are necessary. Hunting frequencies and pull-out torques some thirty per cent in excess of predicted values, for example, indicate considerable error in customary theory. The Blondel theory does give better results in these cases. The phenomena of pull-in torque in motors and instability of generators (pole slipping) are entirely unpredictable except with some form of two-reaction theory such as that proposed by Blondel.

Experimental data for machines operating under demagnetizing conditions are easily obtainable; the methods for securing them and the general character of the results secured are well known, and a theory able to account for the results has been developed which is adequate also as a basis of computation. A very different situation holds for the effects in a synchronous machine under transverse (cross magnetizing) conditions. Enough facts are available, indeed, to show that magnetic conditions are then radically different. A plausible theory has been developed which is applicable to design with some measure of success. However, the writer is unaware of any systematic experimental data which will show what the effect of transverse armature reaction in a synchronous machine is in reality.

The conditions for such an experimental study may be stated very simply. In the first place, the load placed upon the machine should be wholly transverse in effect; that is, the armature currents must attain their maximum value when opposite a pole center. This condition must exist in order that the effects observed shall be due to one cause only, and not complicated by direct magnetization. This carries as a corollary, that the experimental method must have a flexible power factor control; that is, a quick and accurate adjustment of the phase angle of current is needed. In the second place, for an experimental study of transverse reaction, we must be able to measure the terminal voltage of the machine not only in magnitude, but in phase position with reference to the pole axis. In other words, the components of the terminal voltage with reference to the pole axis must be known. Lacking this information, unwarranted assumptions as to the phase angle of the reactance drop would have to be made.

An Experimental Method for Studying Transverse Reaction

The basic idea on which the following experimental method rests is to measure not the voltages and currents of the machine tested but their components with

1. Asst. Prof. of Electrical Engineering, Marquette University, Milwaukee, Wis.

2. *Trans.* Int. Elect. Cong., St. Louis, 1904, Vol. 1, pp. 620-635.

3. Magnetic Circuit Articles 47-48.

4. A. I. E. E. JOURNAL, July 1926 and Oct. 1926.

To be presented at the Winter Convention of the A. I. E. E., New York, N. Y., Feb. 7-11, 1927.

reference to the pole axis—that is, with reference to the no-load voltage of the machine. The second important idea in these experiments is the use of a wattmeter as a device for the measurement of components of voltage and of current.

The machine tested was a 15-kv-a., 6-pole, 60-cycle, synchronous machine rated at 190 volts with its two-phase connection, one of a set of two machines made by the Westinghouse company, for educational institutions. A description of the design details of this machine is in the A. I. E. E. JOURNAL[5]. The diagram

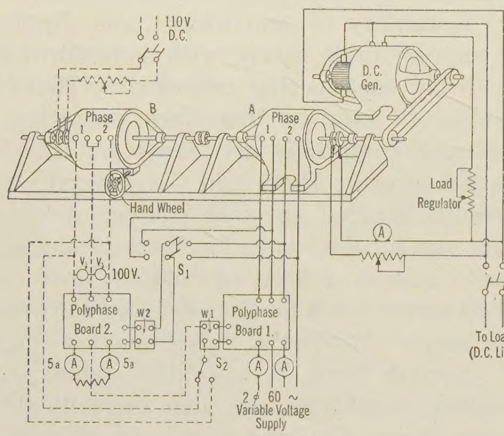

FIG. 1

of connections used is shown in Fig. 1. Machine A was the one tested for its performance, and it was loaded as a motor, by the d-c. generator belted to it. The load on the motor was regulated by the generator field rheostat. The d-c. generator returned its surplus power to the laboratory d-c. line, so that on occasion the set could be run from the d-c. machine as a motor. The current for the synchronous motor A was supplied from the mains of the Milwaukee Electric Co. with 60-cycle current. This current was supplied through a Scott connection and an induction regulator. The voltage supplied could be regulated for any value from 100 to 300 volts. By varying the impressed voltage, the motor could be made to take current at any phase angle desired.

The voltage of machine A was measured by wattmeter (2) excited with five amperes from machine B. Thus the reading of the wattmeter divided by five gave the component of voltage in phase with the excitation. The current in machine A was measured by wattmeter (1) excited with 100 volts from machine B. Thus the reading of this wattmeter divided by 100 gave the component of current in phase with the excitation. Since machine B was loaded on a Cutler-Hammer load rheostat, made of Advance wire wound on flat spools, it was assumed that the excitation of both wattmeters were in the same phase.

Machine B was connected as a two-phase machine, and a double throw switch $S2$ and a polyphase board $P2$ were provided. In this way the excitation of the wattmeters could be transferred to either phase of machine B. The components of current and voltage in machine A were measured, therefore, in two perpendicular phase positions. The double throw switch $S1$ and the polyphase board $P1$ enabled measurements to be taken on both phases of machine A. By adjusting the hand-wheel of machine B, the axes on which the components of current and voltage were read could be brought into any position. The hand-wheel was actually adjusted so that these axes were the same as the voltages of machine A at no load. Thus the wattmeters gave directly the direct and the transverse component of both current and voltage supplied to machine A.

A number of runs were made, each for a definite field current in machine A. In all the runs the induction regulator was adjusted so that the current supplied machine A was wholly transverse in character; that is, wattmeter (1) excited with phase (1) of A and phase (2) of B or *vice versa* read zero. In each run the load was varied from zero to full load. At each load the excitations were checked and all the wattmeter readings taken. The range of field currents used were from 3.25 to 23 amperes, giving saturations of from 100-300 no-load volts.

The data for the two phases were averaged to eliminate small unbalances. The polarities of all the wattmeter combinations were established definitely. The data were corrected for systematic error, including $I\,R$ drop. The data were corrected for other constant errors such as residual demagnetizing currents. The readings of transverse and direct voltage were plotted against transverse current and smooth curves drawn,

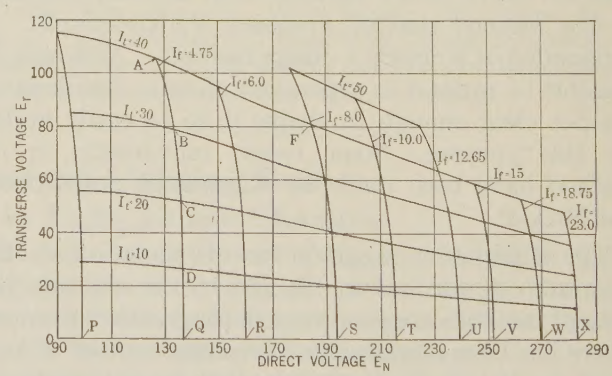

FIG. 2—TRANSVERSE AND DIRECT VOLTAGE WITH TRANSVERSE ARMATURE REACTION

eliminating small observational errors. The data are recorded in graphical form in Fig. 2, and represent the results after correction for the above mentioned errors. The errors were small, and the uncorrected data gave approximately the same set of curves.

DISCUSSION OF THE EXPERIMENTAL DATA

Fig. 2 shows the transverse voltage induced in the machine, under various amounts of transverse mganetizing current, plotted against the direct voltage

5. A. I. E. E. JOURNAL, May 1925, page 543.

induced. The lines sloping downward and to the right are loci for constant values of the transverse current (I_t) of 50, 40, 30, 20 and 10 amperes. The nearly vertical lines are for constant field currents. The direct voltage is designated by the symbol E_n meaning the voltage induced by the net magnetomotive force along the polar axis.

The corresponding loci were calculated from the Blondel theory, using the following data. A demagnetizing reaction equivalent to 7.0 amperes of field current for 40 amperes of demagnetizing armature current, an armature reactance of 0.5 ohm, and a slope of the saturation curve of 31 volts per ampere of field current agree with experimental data in Fig. 5. It was assumed that the transverse reaction was 40 per cent of the direct, and that the armature reactance was a constant. The loci of E_t, for constant transverse magnetizing armature current of 40, 30, 20 and 10 amperes, were lines parallel to the E_n axis and passing through the points A, B, C, and D in Fig. (2). The loci of E_t for constant field current were straight lines perpendicular to the axis E_n and passing through the points P, Q, R, S, T, U, V, W, and X. Even with other assumptions as to the constants, the loci would be a system of lines parallel and perpendicular to the axis E_n. The discrepancy in Fig. 2 between the observed and computed loci is disappointing and does not give promise of any practical method of predicting the effects of transverse reaction from an e. m. f. diagram.

If we analyze Fig. 2 we see several important results. In the first place the transverse voltage for a constant field current is proportional to the transverse armature current. Their constant ratio may be denoted by the symbol X_{st} and may be appropriately called the "transverse synchronous reactance," since it includes the effects of both transverse reactance and transverse reaction.

In the second place, for a constant armature current the tranverse voltage E_t decreases as the saturation

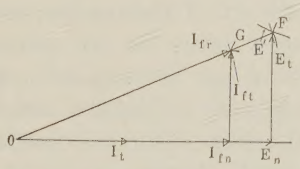

Fig. 3—Derivation of M. M. F. from E. M. F. Diagram

increases. The transverse synchronous reactance is not a constant for different saturations, therefore, but decreases from a value of 3.0 ohms with 3.25 amperes of field current to a value of 1.2 ohms with 23 amperes of field current. The explanation of this phenomenon is simple. The flux set up by transverse reaction is chiefly under the pole tips where the tooth and pole tip iron is affected by the amount of main flux as to saturation.

In the third place, the direct voltage E_n is decreased as the amount of transverse current is increased, even though the field current is constant. This points definitely to a demagnetizing action of the transverse reaction. The voltage E_n, therefore, is not a function of the field current alone. This is shown clearly at all loads and at all field currents, in spite of the fact that there was no demagnetizing current present in the armature. The explanation of this effect is also simple. The cross magnetizing or transverse effect operates to strengthen one pole tip of a pole and to weaken the other; but, owing to saturation, the weakening effect is larger than the strengthening effect. Consequently the

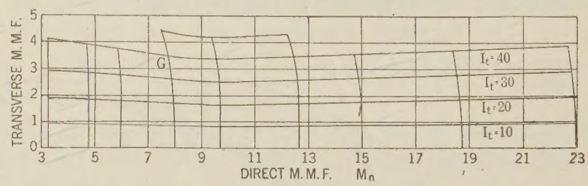

Fig. 4—M. M. F. Diagram of Motor Under Transverse Load

total flux per pole is reduced. The decrease in E_n varies approximately as the square of the current.

The variation in X_{st} with the saturation most seriously affects predictions as to the internal phase angles, but it also affects calculations of needed field current. The variation in E_n affects regulation and field current calculations alone.

It is a mistake to build up a theory of transverse reaction on the basis of an unsaturated magnetic circuit for the transverse flux, since such a theory leads to a constant value of the transverse synchronous reactance. The predicted values of transverse reactance may be correct for some one particular voltage, but at other voltages the performance will be off. For example, in Fig. 2, pull-out torques will be actually larger than computed values for voltages in excess of 130 volts.

The Blondel theory of transverse reaction is in reality a reactance method, since the vectors appearing in the Blondel diagram are $I\,X$ drops. Since the reactances used replace the effects of reaction, the $I\,X$ drops appearing in the diagram are properly termed synchronous reactance drops. It is but natural to turn to an m. m. f. diagram, to see if it gives superior, that is, more constant, results. To convert any point such as F in Fig. 2 into a corresponding point G in a m. m. f. diagram, we use the construction in Fig. 3 and the saturation curve in Fig. 5. We take the voltage E', the resultant of E_n and E_t, to the saturation curve and read there the corresponding resultant magnetomotive force expressed in equivalent field amperes, which we denote by I_{fr}. Since the flux inducing E' is set up by the resultant magnetomotive force, we draw I_{fr} in phase with E'. This magnetomotive force is made up of two components. One produced along the pole axis by the net action of field and direct reaction, we denote by I_{fn}, since it is expressed in equivalent field amperes. The other component of I_{fr} is the trans-

verse m. m. f., which we denote by I_{ft} since it is expressed in equivalent field amperes. Each point in Fig. 2 was converted by this means into a point in the m. m. f. diagram shown in Fig. 4.

Fig. 4 consists of a system of approximately horizontal lines for constant armature current, intersected by a system of approximately vertical lines for constant field current. We may say, therefore, with substantial accuracy, that transverse reaction may be represented on a magnetomotive force diagram, by a vector proportional to the armature current, independent of the field current, and perpendicular to the armature current. Secondary demagnetizing effects do not

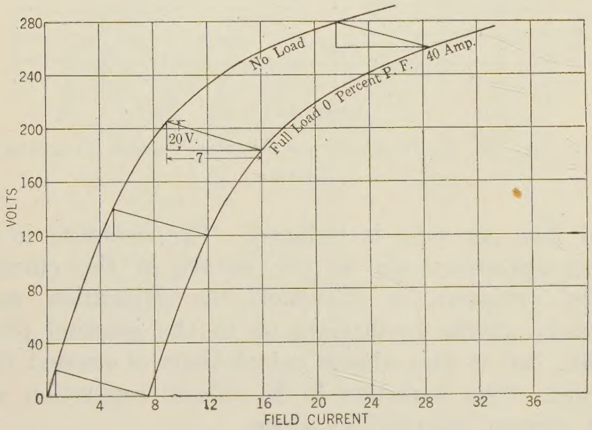

Fig. 5—Saturation Curves

appear on the m. m. f. diagram to any appreciable extent. This diagram proves that we may regard the magnetic flux set up in a machine as produced by a resulting magnetomotive force acting on a single magnetic circuit of substantially uniform saturation. There is no evidence in either Figs. 2 or 3 of any transverse flux component directly proportional to the armature current and independent of saturation. Stated in other words, the transverse leakage reactance X_t appears to be zero; that is, the leakage reactance appears to be less for conductors under the poles than for conductors between the poles. If a transverse leakage reactance existed, the lines in Fig. 4 would all slope upward and to the right. In any machine showing such characteristics, the two effects reactance and reaction could be separated, by trial.

Fig. 5 shows the saturation curves of the machine tested. From it the constants previously used were obtained. We define the experimental coefficients of armature reaction as the ratios of equivalent magnetomotive force expressed in field amperes to armature current. The direct coefficient $C_d = 0.175$, the transverse $C_t = 0.09$, for average conditions in the machines tested. It is worthy of note that the transverse coefficient is approximately one-half the direct coefficient. In solving for the performance of a synchronous machine, for which only the data like that in Fig. 5 were available, the writer would be inclined to use a value of $X_t = 0$ and a value of $C_t = (C_d/2)$. However, it is not permissible to generalize too much from the data on one machine.

Taking the dimensions of the machine and the winding data given by Mr. Quentin Graham[6], the writer has checked the various constants found. The resistance when increased by the A. I. E. E. allowance agrees with the measured value 0.25 ohm per phase. The armature reactance at zero power factor, of 0.5 ohm, checks 25 per cent higher than that computed using Hobart's values of slot and end-connection permeance (10 perms per in. and 2 perms per in.) and somewhat higher than the value computed from data on page 230 of the "Magnetic Circuit."[7] In the equations for direct and transverse reaction given in Karapetoff's "Magnetic Circuit," Art. 49 and 50, we shall for the present take M_d as $N_f\, I_{fd}$ and M_t as $N_f\, I_{ft}$, since the constants there derived are for equivalent field ampere-turns. Thus

$$N_f\, I_{fd} = K_d\, K_b\, K_w\, m\, n\, I_d; \quad N_f\, I_{ft} = K_t\, K_b\, K_w\, m\, n\, I_t \tag{1}$$

We will take $N_f = 185$ turns per pole, $I_{fd} = 7.0$ from Fig. 5, $K_b = 0.907$ for two phases and six slots per pole per phase $K_w = 0.925$ for 75 per cent winding pitch, $m = 2$ phases $n = 22$ equivalent turns per pole per phase for winding undivided in group, $I_d = 40$. The equivalent transverse magnetomotive force corresponding to $I_t = 40$ was taken as 3.6 amperes of field current. Using the above data, the constants are

$$K_d = 0.875; \quad K_t = 0.451 \tag{2}$$

The writer made a careful estimate of the wave of air-gap permeance, the waves of direct, transverse and field flux, analyzing them for their sine wave components, and arrived theoretically at the values

$$K_d = 0.755; \quad K_t = 0.405 \tag{3}$$

It is plain, therefore, that the design constants need experimental correction.

A Theory of Synchronous Machines

It may be presumptuous from the test of one machine to announce a theory of the synchronous machine and give yet another diagram for its performance. However, the results of our tests point very definitely to such a theory and such a diagram, and they are offered for experimental confirmation or rejection. The writer does not have ready access to recent literature, and therefore does not know whether the theory proposed is new or not.

In Fig. 6 the magnetic effect of armature currents in position A is entirely different from that produced by currents in position B. With reference to the pole, the first is transverse, the second is direct. From considerations of symmetry, the armature currents should be resolved into components in these two positions. The magnetic effect of the transverse current in posi-

6. Loc. Cit.

7. Doherty and Nickle's work accounts for some of the discrepancy observed. See paper cited.

tion A is obviously much smaller than that of an equal current acting in position B because it acts on a magnetic path of much higher reluctance.

The magnetic effect of the two components of the armature current may be considered as two-fold; namely, that effect produced individually by each,—that is, as if the other magnetomotive forces were not there,—and that effect produced jointly through the cooperation of the field,—the direct and the transverse currents. Each of the components of armature current may be considered as producing a component of flux, mainly local in character, proportional to the current and independent of saturation, which we may call armature leakage fluxes. They cause a drop in voltage which we may call the leakage reactance drops, each leading its component of current 90 electrical degrees. The direct reactance drop caused by the direct component of current in position B is appreciable, because this drop is due to flux set up in the interpolar regions where there is little interference with the main flux. The transverse reactance drop is small and may be sometimes neglected for the reason that this flux

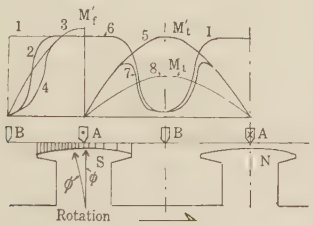

Fig. 6—Theory of Armature Reaction

is set up when the conductors are under the poles and therefore is merged with the main flux[8].

The effect of transverse reaction may also be stated as a distortion of flux. Thus, in Fig. 6 the flux is crowded from the center toward the left-hand pole tips. Although thus displaced in the teeth, air-gap, and pole shoe, the path of the main flux is generally the same under load as under no-load. It is the resultant flux ϕ', for example, in Fig. 6, which induces the voltage at the terminals plus the $I\,R$ and the two $I\,X$ drops. It is the resultant m. m. f. of the machine which produces this resultant flux, and consequently the no-load saturation curve should serve to correlate the induced voltage and the resultant magnetomotive force.

The resultant magnetomotive force may be taken as the vector sum of the three component magnetomotive forces, namely the field, the direct and the transverse magnetomotive forces. Since only sine waves combine to give a sine wave and only sine waves can be represented by vectors, it is obvious that the actual m. m. fs. must be reduced to equivalent sine waves acting upon a uniform active layer. The maximum value of the field, the direct and the transverse magnetomotive forces must therefore each be multiplied by some coefficient to reduce it to the equivalent sine wave m. m. f. applied to a uniform active layer. For the present it is sufficient to notice that the coefficient for the transversely reacting armature current is about one half of that for the directly reacting armature current. Thus the armature reaction is not 90 degrees from the edge of the coil carrying maximum current, but each component of current must be computed separately. The direct reaction ($I_{fd} = C_d\,I_d$) can be combined algebraically with the field current I_f, to get the net m. m. f. along the polar axis I_{fn} in equivalent field amperes; the transverse reaction ($I_{ft} = C_t\,I_t$) must be combined with I_{fn} at right angles to give the magnetomotive force I_{fr}.

Let the maximum values of the actual waves of field, direct and transverse reaction magnetomotive force be M_f', M_d' and M_t'. Let the maximum values of the equivalent sinusoidal m. m. fs. as applied to an active layer of uniform reluctance be M_f, M_d, and M_t. Then we may define three coefficients J_f, J_d, and J_t by the equations

$$M_f = J_f\,M_f'; \; M_d = J_d\,M_d'; \; M_t = J_t\,M_t' \qquad (4)$$

The wave of magnetomotive force of the field is a flat topped wave of maximum value of $M_f' = N_f\,I_f$. The maximum value of the waves of armature reaction are[9]

$$M_d' = 0.9\,K_b\,K_w\,m\,n\,I_d; \; M_t' = 0.9\,K_b\,K_w\,m\,n\,I_t \qquad (5)$$

In Fig. 6, curve (1) is the rectangular wave of field magnetomotive force. Curve 2 is the wave of air-gap permeance for direct flux denoted by $P_d\,(X)$. Curve 2 is also the wave of equivalent field m. m. f. applied to a uniform active layer. Curve 3 is the fundamental sine wave of curve 2, and is the equivalent sinusoidal wave of field m. m. f. as applied to a uniform gap. It is higher than curve 2 because of a prominent fifth harmonic. The constant J_f is the ratio of the maximum value of curve 3 to that of curve 2 and is 1.13 for the machine tested.

If we assume the sine wave curve 3 to be the wave of direct m. m. f. M_f' applied to the machine with curve 2 of direct permeance, the equivalent wave of m. m. f. as applied to a uniform active layer will be curve 4 obtained as a product of curves 2 and 3. If curve 4 be analyzed for its fundamental sine wave, that would be the equivalent sine wave of direct reaction m. m. f. as applied to a uniform gap. This wave is not shown but is some 5 per cent lower than curve 3; that is, $J_d = 0.95$.

Let curve 5 be the wave of actual transverse m. m. f., and curve 6 be the wave of transverse permeance $P_t\,(X)$. The product of curves 5 and 6 will yield curve 7, the wave of equivalent m. m. f. applied to a uniform active layer. Curve 8 is the equivalent sine wave for curve 7 and is much lower

8. Apparently all the fluxes except that due to (X_{ld}) are affected by saturation. This appears to be in contradiction to the assumptions of Doherty and Nickle, in Fig. 27 of paper cited.

9. See Karapetoff's "Magnetic Circuit" Arts.

than curve 5 because of a large third harmonic. The ratio of curve 8 to curve 5 is the coefficient $J_t = 0.51$.

The coefficients J_f, J_d, and J_t are defined by the equations for a Fourier analysis, namely

$$J_f = (2/\pi) \int_0^\pi P_d(x) \sin(x)\, dx \tag{6}$$

$$J_d = (2/\pi) \int_0^\pi P_d(x) \sin^2(x)\, dx \tag{7}$$

$$J_t = (2/\pi) \int_0^\pi P_t(x) \cos^2(x)\, dx \tag{8}$$

$P_t(x)$ is a trifle higher than $P_d(x)$ in the interpolar regions.

The design coefficients used by Professor Karapetoff are defined in terms of the coefficients above as

	Theory	Experiment[10]	
$K_d = 0.9\, J_d/J_f$			
$= 0.9 \times 0.95/1.13 =$	0.755	0.875	(9)
$K_t = 0.9\, J_t/J_f$			
$= 0.9 \times 0.51/1.13 =$	0.405	0.46	(10)

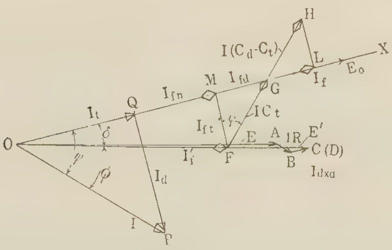

Fig. 7—Proposed Vector Diagram of a Synchronous Machine

A better correspondence could be obtained with experiment if an empirical coefficient were substituted for the rational coefficient 0.9. For our test the value of the coefficient is indicated as approximately unity.

The experimental constants C_d and C_t are most useful even in design calculations; the formulas for these coefficients are

$$C_d = K\, J_b\, K_b\, K_w\, m\, n / J_f\, N_f;$$
$$C_t = K\, J_t\, K_b\, K_w\, m\, n / J_f\, N_f \tag{11}$$

Here K is an empirical factor approximately unity, K_b and K_w are the breadth and winding pitch factors of the winding, m is the number of phases, n is the number of turns per pole per phase, N_f is the number of field turns per pole, and J_f, J_d and J_t are defined by the equations above. If it is not practical to estimate the waves of air-gap permeance in a particular case the values of the J coefficients found here might be used.

Performance Diagram

The problem of finding the performance of a synchronous machine may be formulated thus; Given the terminal voltage, output (input) current and power factor, the no-load saturation curve of the machine, and the constants of the machine, namely R, X_d, X_t, C_d and C_t; it is required to predict the location of the pole axis and find the needed excitation. For definiteness let us find the performance of the machine tested as a generator with normal voltage, normal current, and 86.6 per cent lagging power factor. Let us assume the constants $R = 0.25$, $X_d = 0.50$, $X_t = 0$, $C_d = 0.175$, $C_t = 0.090$.

In Fig. 7 we draw the terminal voltage E from the origin O to the point A, and the current $I = 40$ from O to P lagging E by 30 deg. We draw $A\,B$ equal to the $I\,R$ drop of 10 volts parallel to I. We assume the polar axis $O\,X$ and project P on $O\,X$ giving the direct reacting current $P\,Q$ of 28 amperes. We draw $B\,C$, the direct $I\,X$ drop of $28 \times 0.5 = 14$ volts parallel to $O\,X$. If there were a transverse $I\,X$ drop we would draw it perpendicular to the pole axis arriving at point D. In this case D and C are one point. The line $O\,D$ is the induced voltage E' scaling as 212 volts. We take E' to the saturation curve obtaining the resultant magnetomotive force $I_{fr} = 10.5$ equivalent field amperes, which we lay off along E' from the origin to point F.

We draw $F\,G$ perpendicular to I and equal to $C_t\,I = 0.09 \times 40 = 3.6$ equivalent field amperes, and $F\,H$ in the same direction equal to $C_d\,I = 0.175 \times 40 = 7.0$ equivalent field amperes. We draw the line $O\,G$, which is the pole axis. If serious error was made in assuming $O\,X$, we repeat the work to this point. We project the point H on $O\,G$ giving the point L. The line $O\,L$ is the field current $I_f = 14.2$ amperes. The angle between pole center and the voltage is 14 deg. and the pole center and current is 44 deg.

If we want the regulation we find from I_f that $E_o = 245$ volts and the regulation is 29 per cent. If we want the direct, transverse and net magnetomotive forces, we project F on the pole axis giving point M. The transverse reaction is $F\,M$, the direct reaction is $M\,L$, and the net magnetomotive force is $M\,O$. The formal proof of the above construction is implied in the theory given above; we need only note the following relations:

$$F\,M = F\,G \cos\psi = C_t\,I \cos\psi = C_t\,I_t = I_{ft} \tag{12}$$

$$M\,L = F\,H \sin\psi = C_d\,I \sin\psi = C_d\,I_d = I_{fd} \tag{13}$$

Conclusions

In addition to the conclusions enumerated above, it is hoped that it is now clear that the way is open for a systematic experimental study of the constants of synchronous machines. Studies are needed to determine

1 Whether the performance of a synchronous machine can be predicted with a saturation curve and the five constants R, X_d, X_t, C_d, and C_t.

10. The theoretical coefficient may have to be modified in view of Doherty and Nickle's paper. Priority must be accorded them for certain features of our Fig. 7.

2 Whether there is any definite ratio between X_t and X_d, and if there is any definite ratio between C_t and C_d.

3 What the correlation is between the coefficients C_d and C_t and the design constants.

4 What values of slot and end connection permeance will best check the values of X_d and X_t.

5 What improvements can be made in the experimental method here proposed.

Thanks are due the following Marquette engineering students for assistance in carrying out the tests, making valuable suggestions as to procedure, and pointing out some of the conclusions: Messrs. R. M. Smith, C. McClurg, L. V. Sparks, M. Kempf, F. Stodola.

Voltage Standardization

From a Consulting Engineer's Point of View

BY R. E. ARGERSINGER[1]

Member, A. I. E. E.

Synopsis.—*The author points out certain reasons why specifications for purchased equipment have not followed the manufacturers' existing standards and recommends certain changes in standards for system and apparatus voltages. The importance of having transformers interchangeable as step-up and step-down units is pointed out and, by means of five per cent taps above and below rated voltages in both windings, it is proposed to obtain sufficient flexibility for such interchangeable use. The paper gives a comparison between transformers designed as suggested above and transformers designed according to the manufacturers' recommendations, and the suitability of the suggested tap range is pointed out.*

A recommendation is also made that the number of ratings of oil circuit breakers should be reduced.

VOLTAGE standardization is of value to the consumer principally in two ways; first, that equipment may be used under a variety of operating conditions, and second, that it may be obtained more quickly and at less cost.

If the first result can be secured, the electrical manufacturer's production problems should be so simplified that the second would follow readily. It should be remembered that in discussing the possibility of securing apparatus, such as transformers, at lower prices by standardization, comparisons should be based on the cost of equipment actually purchased at present rather than on the cost of the present standard transformers since it appears that less than half the transformers purchased are standard.

The present standards have not been closely followed because, first, the operating companies in general have given too little consideration to simplifying their requirements, and second, in designing for standardization the manufacturers have placed too much emphasis on cost reduction and have paid too little attention to flexibility of use.

The transmission line data published in the *Electrical World* for January 3, 1925, list eighteen different circuit voltages between 44,000 and 220,000 kv. Other variables have been brought into the situation until one manufacturer now lists 63 different oil circuit breaker ratings between 15,000 and 220,000 volts. Some of these are subject to two and some to three modifications for altitude so that something like one hundred fifty presumably standard breaker ratings are listed for the voltage range indicated, and these do not include the *H* breaker or other low-voltage indoor switches. On the other hand, in their laudable effort to reduce costs, the manufacturers have standardized a range of transformer taps that is not sufficiently flexible for general purposes and have limited too closely the allowable range of terminal voltages.

In the N. E. L. A. *Bulletin* for September, 1926, a proposed plan is offered as a remedy for existing conditions, but it appears to be open to several objections[2]. First, it is not simple; here are at least two, and in most cases three, standard equipment voltages for each system voltage. Second, it is not flexible. Standard transformers and breakers should be interchangeable through the greatest possible number of applications. Transformers should be rated in terms of standard system voltages and should be capable of use between any two systems whose voltages are included in the nameplate rating of the transformer, from which it follows that they should be interchangeable as step-up or step-down units. Third, it does not appear to offer sufficient simplification in manufacturing processes to yield enough benefit to the purchaser to cause him to specify standard equipment.

In an endeavor to meet these objections and at the same time to adhere as closely as possible to present practises, the following scheme is suggested:

First. Standard voltages should be as given in Table I.

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1. Chief Electrical Engineer, Stone & Webster, Inc.

To be presented at the Winter Convention of the A. I. E. E., New York, N. Y., Feb. 7-11, 1927.

2. See also *Voltage Standardization of A-C. Systems from the Viewpoint of the Electrical Manufacturer*, by C. F. Hanker and H. R. Summerhayes, A. I. E. E. Winter Convention, February 1927.

Second. All apparatus except motors should be rated at a standard system voltage.

All motors for use on systems of 600 volts and less should be rated at approximately 8½ per cent less than system voltage. All motors for use on systems above 600 and not exceeding 13,800 volts should be rated at approximately 4½ per cent less than system voltage.

Third. Each winding of all large power transformers should have one full capacity 5 per cent voltage tap above and one full capacity 5 per cent voltage tap below rated voltage. Small power and distribution transformers should be rated in accordance with existing standards.

Fourth. All generators, synchronous condensers, synchronous converters, arc rectifiers, small power and distribution transformers should operate at rated

TABLE I

VOLTAGE		
APPARATUS GENERATOR AND TRANSFORMER	MOTORS	SYSTEM
120	110	120
240	220	240
480	440	480
600	550	600
2300	2200	2300
3980	3800	3980
6900	6600	6900
11500	11000	11500
13800	13200	13800
22000		22000
33000		33000
44000		44000
66000		66000
110000		110000
132000		132000
176000		176000
220000		220000

TABLE II

	SELLING								
	EXISTING SCHEME 4-2½% HT TAPS			PROPOSED SCHEME			SCHEME "A" 1-5% TAP ABOVE & BELOW EACH PRI & SEC VOLTAGE		
	RATED WINDING VOLTS	ACTUAL VOLTAGE	WINDING VOLT ERROR	RATED WINDING VOLTS	ACTUAL VOLTAGE	WINDING VOLT. ERROR	RATED WINDING VOLTS	ACTUAL VOLTS	WINDING VOLT ERROR
GEN	13200	13800	+5 %	13800	13800	0	13800	13800	0
1st SUT	13200	13800	+5 %	13200	13800	+5 %	13100	13800	+5 %
	132000	131200	0 %	132000	131200	−½%	138600	138700	0 %
12 KV DROP									
1st SDT	119000	119200	0 %	113400	119200	+5 %	125400	126700	+1 %
	66000	62800	−5 %	69000	68800	0 %	69300	66500	−4 %
4.5 KV DROP									
2nd S.D.T	59400	58300	−2 %	61000	64300	+5½%	62700	62000	−1 %
	13200	12300	−7 %	13800	13800	0 %	14480	13600	−6 %
600V DROP									
3rd SDT	11900	11700	−1½%	12600	13200	+5 %	13100	13000	−1 %
	2300	2150	−6½%	2400	2400	0 %	2415	2275	−6 %
5% BOOST		2260			2520			2390	
100V DROP									
DISTR TRANS	2300	2160	−6 %	2300	2420	+5 %	2300	2290	0 %
	115	106	−8 %	115	118	+2½%	115	113	−2 %
DROP 3V-TO-LTS 6V-TO-MTS									
LIGHTS	115	103	−10½%	115	115	0 %	115	110	−4½%
MOTORS	110	100	−9 %	110	112	+2 %	110	107	−2½%
	BUYING								
GEN	13200	10900	−17½%	13800	8450	−39 %	13800	13630	−1 %
1st SUT	13200	10900	−17½%	13200	8450	−36 %	14490	13630	−6 %
	119000	104000	−13 %	132000	89000	−32½%	125400	124000	−1 %
12 KV DROP									
1st S.D.T	132000	116000	−13 %	126000	101000	−19½%	138600	136000	−2 %
	66000	61100	−7½%	69000	58200	−15½%	62700	64800	+3½%
4.5 KV DROP									
2nd SDT	66000	65600	−½%	66000	62700	−5 %	69300	69300	0
	13200	13800	+5 %	13800	13800	0	13100	13800	+5 %
GEN.	13200	13800	+5 %	13800	13800	0	13800	13800	0
600V DROP									
3rd SDT	12200	13200	+8 %	12870	13200	+3 %	13100	13200	+1 %
	2300	2365	+3 %	2400	2340	−2	2415	2315	−4 %
5% BOOST		2480			2465			2430	
100V DROP									
DISTR TRANS	2300	2380	+3½%	2300	2365	+3 %	2300	2330	+1½%
	115	117	+1½%	115	116	+1 %	115	114	−1 %
DROP 3V-TO-LTS 6V-TO-MTS									
LIGHTS	115	114	−1 %	115	113	−2 %	115	111	−3½%
MOTORS	110	111	+1 %	110	110	0	110	108	−2 %

5% Drop in each power transformer −2% Drop in distribution transformer, Line drops as indicated.

TABLE III

	OMITTING DISTRIBUTION TRANSFORMER PERCENT SYSTEM VOLTAGE ERROR	PERCENT WINDING ERROR
EXISTING SCHEME	+5 −21	+8 −17½
PROPOSED SCHEME	+4½ −36	+5½ −39
SCHEME "A"	+5 −6	+5 −6
SELLING ONLY EXISTING SCHEME	+4½ −11½	+4½ −7
PROPOSED SCHEME	+4½ −10	+5½ −½
SCHEME "A"	+5 −6	+5 −6

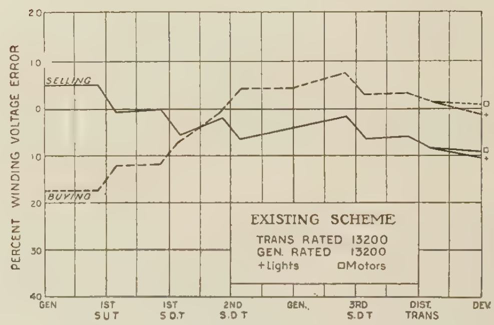

FIG. 1

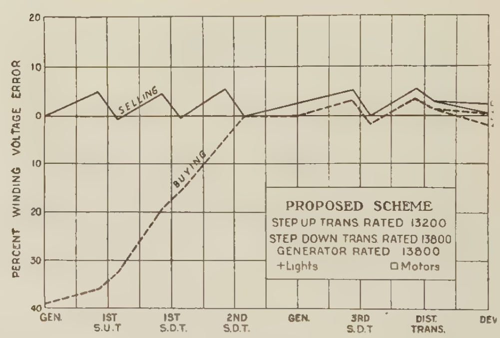

FIG. 2

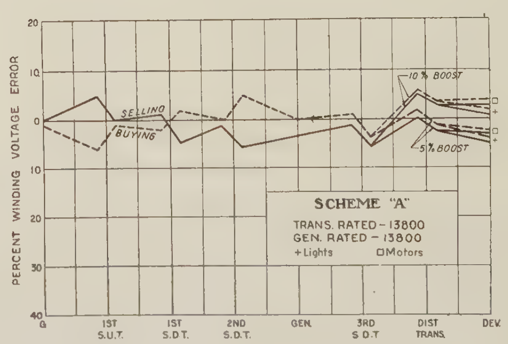

FIG. 3

load without exceeding rated temperature rise through a range of from 95 to 105 per cent rated voltage.

All large power transformers should operate at rated load without exceeding rated temperature rise when excited at 7½ per cent above the rated voltage for the winding terminal to which the circuit is connected.

All motors should operate at rated load without exceeding rated temperature rise through a range of from 90 to 110 per cent rated voltage. All circuit breakers, disconnecting switches, fuses and instrument transformers should operate at rated current without exceeding rated temperature rise when used at 7½ per cent above rated voltage.

Fifth. Proposed definition of rated circuit voltage. Rated voltage of a circuit or system is the highest rated voltage of the apparatus supplying it and should be stated in terms of line-to-line voltage. In order to conform to A. I. E. E. Standards, the dielectric tests of all apparatus connected to a system should be based on rated circuit voltage.

Sixth. The A. I. E. E. standard dielectric tests for oil circuit breakers, disconnecting and horn gap switches and current transformers, should be modified so that all such equipment for use on all system voltages of more than 600 and less than 110,000 will be tested at two and one-half times rated voltage plus 2000 volts, tests for similar equipment built for 110,000 volts and above to remain as at present.

Following the general method outlined in the N. E. L. A. Bulletin, a comparison has been made of system transformer arrangements based on the use of (a) existing standards, (b) those proposed in the Bulletin and (c) those proposed herewith and designated "Scheme A." Conditions which will obtain when buying, as well as when selling, power, have been analyzed. Results are shown in Table II.

Considerable stress has been laid on the matter of buying power because with the rapid increase in system interconnections, it is almost essential to have transformers wound so that they may transfer energy in either direction. It is also desirable, in order to keep pace with the demands of a growing system, to have transformers suitable for transferring from one part of the system to another. All large power transformers should be designed, therefore, for use either as step-up or step-down units.

Curves have been plotted as shown in Figs. 1, 2 and 3 to indicate approximately in per cent the variation of the actual circuit voltage from the winding voltage at various points in the system designated as generator (GEN.) first step-up transformer (1st S. U. T.), first step-down transformer (1st S. D. T.), distribution transformer (DIST. TRANS.), device (DEV.), etc. Fig. 1 gives the variations in per cent between actual voltage and winding voltage when using transformers built to existing standards; Fig. 2, similar data, using transformers as proposed in the Bulletin; and Fig. 3, using transformers according to Scheme A.

Table III shows the maximum variation in per cent between actual circuit voltage and rated circuit voltage measured at the transformers but omitting distribution transformers.

It is possible with transformers designed according to Scheme A that voltages approximately 13 per cent above rating (7½ per cent over-excitation) may be impressed on the winding. It appears that there are many transformers built to existing standards now in operation at equal over-voltages and the record of trouble does not seem to indicate the necessity of increasing the transformer dielectric test. In rating oil circuit breakers at a standard system voltage instead of at a considerable over-voltage, as is the present custom with breakers below 110,000 volts, encroachment should not be made on the existing insulation factor of safety and the proposed change in the circuit breaker dielectric test therefore has been offered.

While not strictly a matter of voltage standardization, there is an opportunity for a very considerable reduction in the number of standard circuit breaker ratings if careful standardization is undertaken. By following the proposed system voltages and by elimination of many current, as well as rupturing capacity ratings, the number of standard ratings and list of standard breakers could be so shortened that the increase in production of breakers having duplicate ratings should produce a considerable reduction in manufacturing costs.

CONCLUSIONS

The data seem to indicate that the so-called Scheme A is preferable for the following reasons:

First. The number of standard voltage ratings is reduced.

Second. The flexibility of apparatus is increased. The transformers are practically interchangeable as step-up or step-down units and should be suitable for use on any well-designed system of the same rated voltage.

Third. The rated voltages of the transformers are close to the corresponding rated system voltages.

Fourth. The actual operating voltages are close to the winding voltage.

When will the city streets of America be lighted by lamps connected to the power plant by radio? Senatore Marconi, one of the originators of "wireless," cannot supply the answer but he ventures the prophesy that this sort of thing will come about, and that it is not too visionary to believe that electric power will be transmitted short distances without wires and cables as from a waterfall to a nearby city but he cannot think the day will soon come when power will be distributed everywhere by radio.

The M. M. F. Wave of Polyphase Windings

With Special Reference to Sub-Synchronous Harmonics

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Associate, A. I. E. E.

Synopsis.—The m. m. f. waves of fractional slot windings or other irregular windings are found to contain harmonic components having wavelengths greater than two pole pitches. These are designated as sub-synchronous harmonics since their harmonic order is lower than that of the synchronously rotating wave. They induce currents in the damper windings of synchronous machines which may produce noticeable loss. Some test data concerning losses are included. These harmonics have an effect upon reactance and, under certain conditions, they may cause vibration. An appendix covers the calculation of the m. m. f. of three-phase fractional slot machines.

* * * * *

THE m. m. f. wave shapes of polyphase windings have been investigated by numerous writers.[2] The methods of analysis vary somewhat but the results are essentially the same. It is known, for example, that with the usual three-phase winding, the m. m. f. wave consists of a fundamental sinusoidal wave traveling uniformly at synchronous speed and certain odd multiples of the fundamental. Of these higher harmonic components, it is easily shown that the third or multiples thereof do not exist, and that the 5th, 11th, 17th, etc., travel against rotation while the 7th, 13th, 19th, etc., travel with rotation or in the same direction as the fundamental wave. The speed at which these components of the m. m. f. wave travel is inversely as their harmonic order. Thus the 5th harmonic travels at one-fifth synchronous speed, the 7th harmonic at one-seventh speed and so on. Each component moves through its own wavelength in the same interval of time.

In the present paper, the m. m. f. waves of certain particular types of windings are examined in some detail and it is shown that they possess additional harmonics which may have an important bearing on machine performance. The paper deals chiefly with fractional slot windings.

The term "fractional slot" is applied to machines in which the ratio of the number of slots to the number of poles is not an integral number. In machines of this type the m. m. f. wave varies from pole to pole. Thus when the m. m. f. for the complete armature is plotted and the wave analyzed, it is found to contain harmonic components having a wavelength greater than twice the pole pitch. That is, there are harmonics of lower order than the predominant component which travels at synchronous speed and which is normally spoken of as the fundamental wave. It becomes convenient, then, to use a new rotation in which the complete developed armature is taken as 2π radians and the fundamental component of the m. m. f. is a wave whose length is 2π. The complete m. m. f. wave contains components which are various multiples of this fundamental, one of which is the synchronously rotating wave. The synchronous component, which in usual notation is the fundamental wave, now becomes the $\frac{P}{2}$th harmonic, where P is the number of poles. There may be other component waves having harmonic orders below the $\frac{P}{2}$th or synchronous component and there will always be components of higher order.

The existence of these components of low harmonic order in the m. m. f. wave of fractional slot and other irregular windings has not been noted previously, as far as I am aware.[3] For convenience in distinguishing them from the usual higher harmonic components, I have used the term "sub-synchronous harmonics" since their harmonic order is below that of the synchronous component. This term is not entirely satisfactory since there may be important components whose order is above the synchronous component but which are not multiples thereof. The term "non-synchronous harmonic" may be used to designate any component other than the synchronous and of course is applicable to the 5th, 7th, etc., which occur in integral slot three-phase machines.

It is interesting to examine the sub-synchronous harmonics with reference to their speed of rotation and their direction. It is well known that the usual higher harmonics proceed around the armature at less than synchronous speed, each moving its own wavelength during a cycle of the current. It is not surprising, then, to find that the sub-synchronous harmonics travel at higher speeds, fulfilling the same condition of one wavelength of travel during one cycle of current. The direction is found to be with rotation in some cases

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2. See, for example, "The Mathematical Treatment of the Magnetomotive Force of Armature Windings" by B. Hague in the JOURNAL of the Institution of Electrical Engineers, July, 1917

To be presented at the Winter Convention of the A. I. E. E., New York, N. Y., Feb. 7-11, 1927.

3. While the present paper was being prepared, the existence of these harmonics was mentioned in a footnote by Doherty and Nickle in their paper, *Synchronous Machines*, presented at the June 1926 Convention of the A. I. E. E.

and against rotation in others, as will be shown later.

The method of determining the existence of any harmonic and of finding its magnitude will be shown in detail. The fluxes which correspond to the various harmonics will then be considered. The effect of these fluxes in both the stator and rotor will be discussed and it will be shown that they have an influence upon reactance and upon losses.

Determination of M. M. F.

A balanced polyphase winding having an integral number of slots per pole and equal spacing of phase

Fig. 1—M. M. F. of Full Pitch Coil

belt produces an m. m. f. wave in which the space distribution is repeated for every pair of poles. For this type of winding it is sufficient to plot the m. m. f. for two pole pitches and to base all analyses of armature reaction on an equivalent two-pole machine. For the type of windings under consideration, however, the m. m. f. distribution varies from pole to pole around the armature so it becomes necessary to consider the entire winding. The method of analysis used here consists in finding, first, the m. m. f. wave set up by a single coil. This is decomposed into its various harmonic components after which each component is added separately to the corresponding waves of the other coils.

Consider for the moment a developed armature such as is shown in Fig. 1 with a coil having a pitch equal to

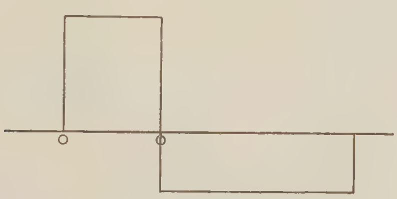


Fig. 2—M. M. F. of Short Throw Coil

half of the developed length. This may be, for example, a two-pole machine with a full pitch coil. The m. m. f. set up by this coil has a space distributed shown by the rectangular wave. It is well known that such a wave can be expressed as

$$a = \frac{4}{\pi}\left(\sin \alpha + \frac{1}{3} \sin 3\,\alpha + \frac{1}{5} \sin 5\,\alpha \;.\;.\;.\; \frac{1}{n} \sin n\,\alpha\right)$$

Suppose now that the throw of the coil is less than half of the developed armature. The m. m. f. form then takes the unsymmetrical rectangular shape shown in Fig. 2. The areas under both halves of this wave are equal and the ratio of the positive to the negative ordinates varies with the angle β which expresses the coil throw. The magnitude of any harmonic component of a wave of this type is shown, in Appendix A, to be

$$a_r = \frac{0.45}{n} \sqrt{1 - \cos n\,\beta} \tag{5}$$

In this case both odd and even harmonics may be present. However, if the armature shown in Fig. 2 is used to represent a two-pole machine with short throw coils and the usual balanced arrangement of slots and phases, the even harmonics will not appear in the final m. m. f. wave due to a cancellation that takes place when the components of all coils are added. This is in agreement with the well known fact that chording a winding changes the magnitude of the m. m. f. but does not introduce dissymetry.

Let another developed armature be represented by Fig. 3. In this case the complete machine has a large number of poles and the throw of the single coil shown is small compared to the complete developed armature.

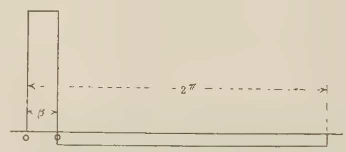


Fig. 3—M. M. F. of Single Coil of a Multipole Machine

For purposes of analysis, however, the coil may be considered just as if it were a coil of extremely short throw on a two-pole armature. The angle of throw of the coil is β and the complete armature span is taken as $2\,\pi$. The values of the different harmonics are found from (5). The component of lowest harmonic order will have a length equal to the complete armature; that is, it will be the fundamental wave and the other component waves will have harmonic orders which are multiples of its order.

The problem then resolves itself into locating all the other coils in their correct positions and adding

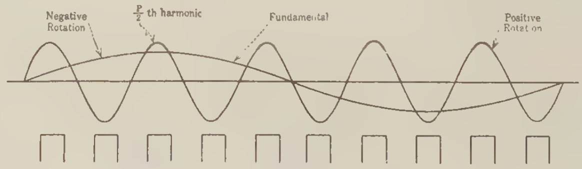


Fig. 4

together the waves of the same harmonic order. Appendix B shows the method of carrying out this calculation for the case of fractional slot, three-phase windings. Fig. 4 shows the fundamental wave and the $\frac{P}{2}$th or synchronous harmonic for a 10-pole machine. The magnitude of the fundamental is exaggerated in the sketch.

If the same method of analysis were applied to a winding which is not of the irregular type, the harmonics of lower orders appearing in the m. m. f. of a single coil would cancel out when combined with those of the other coils. This is simply stating that when the armature winding for one pair of poles is the same as for every other pair of poles, the m. m. f. wave repeats itself for each pair of poles.

Fractional Slot Windings

Modern a-c. machines make extensive use of windings in which the number of slots per pole is not an integer. These fractional slot windings give perfectly balanced terminal voltages and usually produce voltage wave shapes which are noticeably free from harmonics. There are many design and manufacturing advantages in the use of these windings since the possible numbers of slots for a given machine is not limited to multiples of the number of poles.

The method of determining the possible numbers of slots for any combination of poles and phases and of distributing the coils so as to obtain balanced voltages, has been published[4] previously. For three-phase

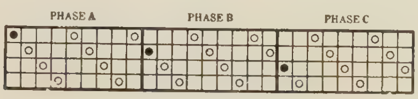


Fig. 5—Winding Chart for Machine with 6¾ Slots per Pole $(y-4)$

Chart covers one repeatable group for each phase. It is applicable to any machine having the same number of slots per pole and having a number of poles which is a mutiple of 4. The beginning of each phase is shown by the symbol •

windings the rule is that the number of slots must contain the factor $3^{(r+1)}$ where r is the number of times the factor 3 appears in the number of poles. The distribution of coils into pole groups is illustrated by the chart in Fig. 5. The procedure to be followed in laying out such a chart can be explained more easily by the use of an example.

Let us take a 20-pole, three-phase machine having 135 slots. The number of slots per phase per pole expressed as a fraction is 9/4. Select a scale such that four divisions equal a slot pitch. Then nine divisions will represent a phase belt and 27 divisions a complete pole pitch. Locate the conductors a slot pitch apart on the chart, regardless of their relation to the phase belts, placing the succeeding poles under the first pole. Continue this until it is seen that the positions of the conductors along the horizontal scale are the same as those at the beginning of the chart. It will be found that four pole pitches must be covered before the winding begins to repeat. In any winding of this type the number of poles passed through before the winding repeats is the same as the denominator of the fraction expressing the slots per pole per phase. In the discussion that follows, y will be used to represent this number of poles.

The winding chart, Fig. 5, now shows the number of slots to be used in each phase group under each pole. The first pole will have 3 coils in phase A, 2 in phase B and 2 in phase C; the second pole will have 2 coils in phase A, 3 in phase B and 2 in phase C; and so on. Each group of 4 poles will be a repetition of the first 4 poles. Since there are 20 poles in the machine there will be 5 equal groups. These groups may be in series or parallel connection. The term "repeatable group" is used here to designate the coils of one phase in the 4, or in general, y, adjacent poles.

In the determination of the m. m. f. waves as shown in Appendix B, the angular position of each coil in a repeatable group with reference to the initial coil must be found from the winding chart. In Fig. 5 the angular positions of the coils in phase A with respect to the first coil are as shown below. All angles are multiples of the slot pitch except that the angle π has been added to the actual physical position of coils in alternate poles to take into account the reversal of the direction of current in those coils. Letting S represent a slot pitch in angular measure the angles with respect to the nth harmonic wave length are:

	Angles
Coil No. 1..................	0
Coil No. 2..................	$n\,s$
Coil No. 3..................	$2\,n\,s$
Coil No. 4..................	$7\,n\,s + \pi$
Coil No. 5..................	$8\,n\,s + \pi$
Coil No. 6..................	$14\,n\,s$
Coil No. 7..................	$15\,n\,s$
Coil No. 8..................	$21\,n\,s + \pi$
Coil No. 9..................	$22\,n\,s + \pi$

These are the angles to be used in adding the m. m. f. waves of the individual coils to obtain the quantity M used in Appendix B.

While the determination of the magnitude of any harmonic component in the final m. m. f. wave is rather tedious, the test for the existence of any harmonic is quite simple. It is shown in Appendix B that if

$$\frac{n + \frac{P}{2}}{\frac{P}{y}} = K_1 \qquad (21)$$

and if

$$\frac{y\,(P \pm 2\,n)}{6\,P} = K_2 \qquad (22)$$

where K_1 and K_2 are integers, including zero, the nth harmonic exists. Otherwise, although it is present in the coil m. m. f., it is cancelled when the summation is made.

4. See "Two- and Three-Phase Lap Windings in Unequal Groups," by E. M. Tingley, *Electric Review and Western Electrician*, Vol. 66, No. 4.

Table I shows the magnitude of the sub-synchronous harmonics in the m. m. f. waves of a number of typical fractional slot machines. All of these windings fulfill the conditions necessary to obtain balanced terminal voltages. The value of each harmonic is expressed in per cent of the synchronous component.

TABLE I

No. poles	No. slots per pole per phase	Per cent harmonics total	Per cent harmonics		
10	4- 2/5	3.6	3.6_1		
10	4- 4/5	5.2	5.2_1		
22	1- 7/11	15.9	4.2_1	4.4_5	7.3_7
24	3- 3/8	6.6	3.4_3	3.2_6	
26	2-10/13	14.4	2.1_1	7.7_5	2.2_7
			2.4_{11}		
44	2- 1/22	28.8	3.3_2	4.1_4	2.6_8
			5.8_{10}	2.0_{14}	9.5_{16}
			1.5_{20}		
48	2- 1/4	11.0	11.0_{12}		
72	1- 3/4	14.3	14.3_{18}		

This table shows the value of the sub-synchronous harmonics in per cent of the synchronous m. m. f. The subscripts indicate the order of the harmonic. All machines listed are three-phase. Harmonics of orders higher than that of the synchronous component but not multiples of it are not shown, although they may exist and may be, in some cases, as important as those that are sub-synchronous.

Effect of Sub-Synchronous Harmonics on Performance

When the existence of m. m. f. waves of low harmonic order has been established, there arises the question of their possible effects on performance. The equations in Appendix B show that these waves, like the usual higher harmonics, have speeds proportional to $\frac{1}{n}$. They set up corresponding flux waves, assuming constant permeance of the gap, which induce voltages of line frequency in the armature conductors. Thus they add to the reactance of the machine. Their speed relative to the rotor (of a synchronous machine) is such as to develop in the rotor windings voltages of frequency f_n where

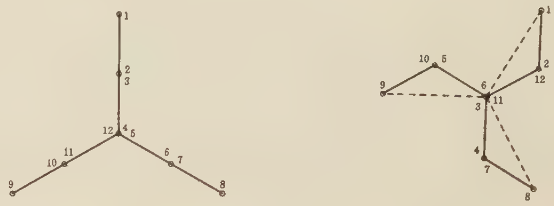
$$f_n = f\left(\frac{2\,n}{P} \pm 1\right)$$

In a machine having a damper winding there will be secondary currents of this frequency which will react on the stator and reduce the value of the corresponding flux wave. The possible sources of loss, then, are $I^2 r$ loss in the damper winding, if the machine has one, and iron loss in both the stator and the rotor.

Losses. It seems probable that the presence of sub-synchronous harmonics in the m. m. f. wave may cause appreciable rotor loss, particularly in machines having damper windings. It is important to note that the frequency of the induced rotor currents, for any sub-synchronous harmonic, is between zero and 200 per cent of the line frequency, as shown by the expression

$$f_n = f\left(\frac{2\,n}{P} \pm 1\right)$$

The damper winding loss of single-phase machines is caused by rotor currents of 200 per cent frequency and there are plenty of data to show that this loss may be an important factor in the efficiency. It is true that the magnitude of the non-synchronous component of m. m. f. in a single-phase machine is equal to the synchronous component and therefore is greater than in any



A B

FIG. 6

A—STAR-CONNECTED WINDING

B—INTERCONNECTED STAR WINDING

of the polyphase machines under consideration. But with a total of, say, 20 per cent harmonic m. m. f., which may easily exist, causing rotor currents of various frequencies between zero and 200 per cent, it is reasonable to believe the losses may be appreciable. It is interesting to note in passing that the space harmonics of integral slot three-phase windings, those of 5th, 7th, 11th, 13th, etc., harmonic order compared to the synchronous component, cause rotor currents of six times normal frequency or multiples thereof and

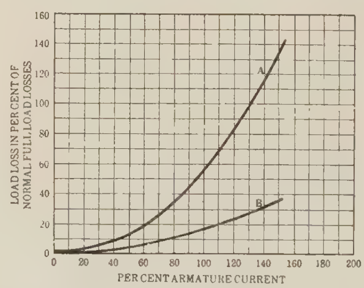


FIG. 7—MACHINE EQUIPPED WITH DAMPER WINDING

Curve A, loss with winding connected to produce sub-synchronous harmonics.

Curve B, loss with normal windings.

thus operate on relatively high impedance circuits and produce negligible loss.

In order to obtain test data bearing on the question of losses, a normal three-phase machine with an integral number of slots was reconnected according to the diagram in Fig. 6. This type of connection, which has had some practical use, is usually called an interconnected star. It gives a simple means of changing a star-connected machine so as to have 86.6 per cent of the effective turns. In making this connection, however, the armature m. m. f. is unbalanced in such a way that sub-synchronous harmonics are set up. Table II gives the values of the various components. It will be seen that both the fundamental and the

third harmonic have positive and negative waves. These arise because the space positions of the phases are no longer symmetrical, whereas the phase groups of fractional slot windings are always equally spaced. For our purpose, however, it is not necessary that a given harmonic have only one direction of travel.

Curve *A* in Fig. 7 gives the total load loss[5] of this machine with the interconnected star winding. Curve *B* gives the load loss with the winding arranged in star connection but with 120-deg. grouping so as to obtain the same synchronous m. m. f. per ampere as with the interconnected winding. The 120-deg. grouping gives an m. m. f. wave, free from sub-synchronous components, just as in the usual 60-deg. winding. The curves give a direct measure of the increased loss due to the presence of harmonics of lower order. At rated current the load loss increased to 3.6 times its normal value.[6] The sum of the four components given in Table II is 65.9 per cent which is more than double that of any of the machines listed in Table I. It is, of course, an exceptionally flagrant case of unbalanced m. m. f. but it indicates that machines with lower values of harmonics may be worthy of study.

TABLE II

No. Poles	No. slots per pole per phase	Per cent harmonics total	Per cent harmonics
8	4	65.9	7.7_{+1} 5.6_{-1} 41.6_{+3} 11.0_{-3}

Harmonics present with interconnected star winding. Values are given in per cent of the synchronous m. m. f. Positive and negative waves of the same harmonic order are present.

An attempt was made to simulate the conditions in the rotor due to these harmonics by applying various frequencies to the stator winding, with the normal star connection, and with the rotor locked. In this way currents of any desired frequency may be set up in the rotor bars and the loss in the rotor may be determined. It is realized that the distribution of current in the rotor is affected by the wavelength of the flux wave which induces the current, so that even though the frequency is the same, the loss may be slightly different. The test results, which were not particularly accurate, showed that about 70 per cent of the increased load loss could be accounted for as loss in the rotor.

A similar test was made on another machine giving the results shown in Fig. 8. In this case the load loss at rated current increased many times due to the fact that the normal load loss was almost negligible. While this was a much smaller machine than was used in the preceding test, the number of poles and number of slots were the same and the per cent of harmonic m. m. fs. given in Table II holds for this case also.

5. The load loss is the difference between the measured short-circuit loss and the armature $I^2 R$ loss.

6. In an unpublished report written by Mr. M. W. Smith during 1921, the existence of high load loss in machines with interconnected star windings was noted and was explained by means of a graphical plot of the m. m. f. wave.

Load loss tests made on machines such as those listed in Table I have not given convincing data concerning the additional losses due to harmonics in the m. m. f. This has been due partly to the fact that most of the machines with high percentages of harmonics have been in the low speed class where the total load loss is small and difficult to measure with accuracy. A comparison of losses of similar machines, one with and one without harmonics, is not sufficient since a change in number of slots is always involved. With the present knowledge of load losses it is usually impossible to take into account these changes in magnetic proportions and thereby segregate particular losses. The data given in this paper are offered simply as evidence that there is a possibility of additional losses due to m. m. f. harmonics when irregular windings are used. Further study is needed to determine how important these losses are.

Reactance Voltage. The method of finding the reactance voltage due to any particular harmonic is shown in Appendix B for the case in which there is no opposing rotor current. The equations show that the voltages due to the various harmonics are not in phase with one

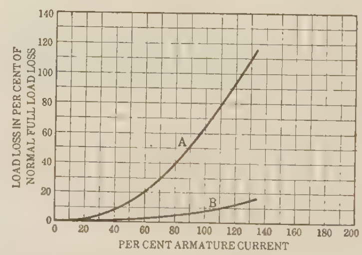


Fig. 8—Machine Equipped With Damper Winding

Curve A, loss with winding connected to produce subsynchronous harmonics.
Curve B, loss with normal windings.

another. The total reactance voltage due to m. m. f. harmonics may be found by adding together, in the proper phase relation, the various component voltages.

What may be said of the magnitude of the reactance voltage calculated in this manner? At first glance it would appear that fairly large values are to be expected considering the amplitude of the non-synchronous flux waves. However, when the actual interlinkages are worked out the result is found to be quite low. In the machines that have been examined up to the present time, all of them salient pole synchronous machines, the total reactance voltage due to m. m. f. harmonics has been less than one per cent of rated voltage. It appears, therefore, that this part of the reactance is of no great importance. The whole subject of reactance, particularly that of fractional slot machines, is being investigated by other engineers and it is possible that, eventually, the factors treated here will assume more importance than appears likely at present.

Vibration. Severe vibration of the stator of a small machine having a fractional slot winding was largely responsible for the present investigation of m. m. f. forms. This particular machine had a fundamental wave of about four per cent of the synchronous component. This wave might be replaced by an equivalent two-pole rotor revolving at 3600 rev. per min. (for 60-cycle supply). Thus there were variations in magnetic attraction, tending to distort the stator at its weakest section, which occurred 120 times a second. Measurement by means of a torsiograph showed vibrations of exactly this frequency. Further tests showed that the natural frequency of vibration of the stator was almost identical with the forced vibration. A minor change in construction was sufficient to remove the natural frequency from the danger zone and stop the vibration. Such a coincidence of natural and forced frequency is probably rare but the experience indicates another of the possible effects of lower order harmonics.

ACKNOWLEDGMENTS

I am indebted to Mr. H. Brookins for assistance in working out the data in Table I and to Mr. H. V. Putman and Mr. C. M. Laffoon for much valuable criticism.

Appendix A

M. M. F. OF A SINGLE COIL

Let the coil shown in Fig. 3 be excited with unit current. Assume that the air-gap is uniform and that the iron is unsaturated. The flux set up by this coil must pass across the gap in one direction over the space between zero and β and return between β and 2π. We can then draw a rectangular wave, representing the density, in which the areas under the two half waves are equal. With a uniform gap this curve may be used to represent m. m. f. also. Let the total m. m. f. of the coil be unity. Then if the positive ordinate of the wave is h, the negative ordinate will be $(h - 1)$. The wave may be expressed as

$$f(\alpha) = \Big[h \Big]_{\alpha=0}^{\alpha=\beta} + \Big[h - 1 \Big]_{\alpha=\beta}^{\alpha=2\pi} \qquad (1)$$

The value of the sine component of any harmonic of a periodic function is known to be

$$a_s = \frac{1}{\pi} \int_0^{2\pi} f(\alpha) \sin(n\,\alpha)\, d\,\alpha$$

or, in this case,

$$a_s = \frac{1}{\pi} \int_0^{\beta} h \sin(n\,\alpha)\, d\,\alpha + \frac{1}{\pi} \int_{\beta}^{2\pi} (h-1) \sin(n\,\alpha)\, d\,\alpha \qquad (2)$$

Integrating,

$$a_s = \frac{1}{n\,\pi}(1 - \cos n\beta) \qquad (3)$$

Similarly, the cosine component is found to be

$$a_c = \frac{1}{n\,\pi} \sin n\,\beta \qquad (4)$$

The resultant value of the nth harmonic is

$$a_r = \sqrt{a_s^2 + a_c^2}$$

or,

$$a_r = \frac{1}{n\,\pi} \sqrt{(1 - \cos n\,\beta)^2 + (\sin n\,\beta)^2}$$

Solving,

$$a_r = \frac{0.45}{n} \sqrt{1 - \cos n\,\beta} \qquad (5)$$

The zero point of the resultant wave is displaced from the origin by the angle,

$$\theta_n = \tan^{-1} \frac{a_c}{a_s}$$

$$\theta_n = \tan^{-1} \frac{\sin n\,\beta}{1 - \cos n\,\beta} \qquad (6)$$

Appendix B

M. M. F. AND REACTANCE VOLTAGE OF FRACTIONAL-SLOT, THREE-PHASE WINDINGS

Let the coil shown in Fig. 3 be excited with a current equal to $\sqrt{2} \sin \omega\, t$. The maximum ordinate of the nth harmonic wave will be, from equation (5),

$$\frac{0.45 \sqrt{2}}{n} \sqrt{1 - \cos n\,\beta} \sin \omega\, t$$

At any point in space the ordinate of the wave will be

$$a_1 = \frac{0.636}{n} \sqrt{1 - \cos n\,\beta} \sin \omega\, t \sin n\,(\alpha - \theta_n) \qquad (7)$$

since the zero point of the wave is displaced from the origin by the angle θ_n.

For any other coil in the same phase the nth harmonic wave is expressed by

$$a_2 = \frac{0.636}{n} \sqrt{1 - \cos n\,\beta} \sin \omega\, t \sin n\,(\alpha - \theta_n - \phi_2) \qquad (8)$$

where ϕ_2 is the angle between that coil and the origin.

To find the combined nth harmonic wave due to the entire phase it is necessary to add the single coil waves in proper angular relationship. These individual coil waves are all equal in magnitude but are spaced in irregular fashion. To find the resultant wave it is convenient to consider the waves as vectors of equal length separated from the zero vector by various angles corresponding to the positions of the coils with respect to the reference coil. It is necessary to consider only the coils in one repeatable group instead of the whole phase, as will be shown later. The actual angles must

be obtained from the winding chart. These vectors are then added and the resultant is determined both in magnitude and position. If M is taken as the ratio of the length of this resultant vector to the length of a single vector and $n\,\psi$ is the angle that the resultant makes with the zero vector, the equation for the m. m. f. of a repeatable group is

$$a_g = \frac{0.636\,M}{n}\sqrt{1-\cos n\beta}\,\sin\omega t \sin n(\alpha-\theta_n-\psi) \quad (9)$$

The quantities M and $n\,\psi$ must be determined in each case by performing the vector addition. This is the laborious part of working out the m. m. f. wave for any particular harmonic. Each phase contains $\frac{P}{y}$ repeatable groups. The angle between the beginnings of these groups is $\frac{y\,2\,\pi}{P}$. If y, which is equal to the number of poles per group, is an even number, the angle between the nth harmonic waves of adjacent groups is also $\frac{y\,2\,\pi}{P}$.

However, since y may be odd, the waves of adjacent repeatable groups may be reversed due to the fact that alternate pole groups are wound in opposite directions. This may be taken into account by writing the angular space between the nth harmonic waves of adjacent repeatable groups as

$$\frac{y\,2\,\pi}{P} + \frac{y\,\pi}{n}$$

or $\left(\dfrac{n+\frac{P}{2}}{\frac{P}{y}}\right)$ nth harmonic wavelengths.

Since both numerator and denominator of this fraction are known to be integers, we may write

$$\frac{n+\frac{P}{2}}{P/y} = K_1 + \frac{K_2}{P/y} \quad (10)$$

where K_1 is any integer and K_2 is any integer less than P/y including zero.

If $K_2 = 0$, the angle between the waves of the various repeatable groups is an integral number of wavelengths and the waves add arithmetically. If, on the other hand, K_2 is not zero, the $\frac{P}{y}$ waves are spaced by equal multiples of $\frac{y\,2\,\pi}{n\,P}$ and must add up to zero.

Thus when $\dfrac{n+\frac{P}{2}}{P/y}$ is an integer, the resultant wave for the whole phase becomes

$$a_{p1} = \frac{0.636\,M\,P}{n\,y}\sqrt{1-\cos n\,\beta}\,\sin\,\omega\,t\,\sin\,n(\alpha-\theta_n-\psi) \quad (11)$$

And, when $\dfrac{n+\frac{P}{2}}{P/y}$ is not an integer, the nth harmonic is not present in the m. m. f. wave.

The next step is to combine the wave set up by the first phase with the corresponding waves of the other phases. In a fractional-slot, three-phase winding the beginning of the second phase is at an angle $\frac{y\,2\,\pi}{3\,P}$ from the beginning of the first phase, as can be seen from the winding chart. The beginning of phase 2 is understood to be the point from which the subsequent pole groupings for that phase follow the same sequence as in the first phase when starting from the original reference coil.

The time phase of the current in phase 2 may be expressed by $\left(\omega\,t - \frac{y\,2\,\pi}{6}\right)$ since, as the winding chart shows, there are y pole phase groups between the starting points.

The equation for the nth harmonic wave of phase 2 is, then,

$$a_{p2} = \frac{0.636\,M\,P}{n\,y}\sqrt{1-\cos n\,\beta}\,\sin\left(\omega\,t-\frac{2\,\pi\,y}{6}\right)\sin n\left(\alpha-\theta_n-\psi-\frac{2\,\pi\,y}{3\,P}\right) \quad (12)$$

and similarly, for phase 3,

$$a_{p3} = \frac{0.636\,M\,P}{n\,y}\sqrt{1-\cos n\,\beta}\,\sin\left(\omega\,t-\frac{4\,\pi\,y}{6}\right)\sin n\left(\alpha-\theta_n-\psi-\frac{4\,\pi\,y}{3\,P}\right) \quad (13)$$

For convenience, let

$$C = \frac{0.636\,M\,P}{n\,y}\sqrt{1-\cos n\,\beta}$$

and

$$D = (\alpha-\theta_n-\psi)$$

Then, substituting C and D in equations (**11**), (**12**) and (**13**) and expanding,

$$a_{p1} = \frac{C}{2}\left[\cos(\omega t - nD) - \cos(\omega t + nD)\right] \quad (14)$$

$$a_{p2} = \frac{C}{2}\left[\cos\left(\omega t - \frac{2\pi y}{6} - nD + \frac{2\pi y n}{3P}\right)\right.$$
$$\left. - \cos\left(\omega t - \frac{2\pi y}{6} + nD - \frac{2\pi y n}{3P}\right)\right] \quad (15)$$

$$a_{p3} = \frac{C}{2}\left[\cos\left(\omega t - \frac{4\pi y}{6} - nD + \frac{4\pi y n}{3P}\right)\right.$$
$$\left. - \cos\left(\omega t - \frac{4\pi y}{6} + nD - \frac{4\pi y n}{3P}\right)\right] \quad (16)$$

The sum of the waves of the three phases will give the final resultant wave for the whole armature. Adding a_{p1}, a_{p2} and a_{p3},

$$a_n = \frac{C}{2}\left[\cos(\omega t - nD)\right.$$
$$+ \cos\left(\omega t - \frac{2\pi y}{6} - nD + \frac{2\pi y n}{3P}\right)$$
$$\left. + \cos\left(\omega t - \frac{4\pi y}{6} - nD + \frac{4\pi y n}{3P}\right)\right]$$
$$- \frac{C}{2}\left[\cos(\omega t + nD\right.$$
$$+ \cos\left(\omega t - \frac{2\pi y}{6} + nD - \frac{2\pi y n}{3P}\right)$$
$$\left. + \cos\left(\omega t - \frac{4\pi y}{6} + nD - \frac{4\pi y n}{3P}\right)\right] \quad (17)$$

It will be observed that if

$$-\frac{y}{6} + \frac{y n}{3P} = K_1$$

where K_1 is any integer, including zero, equation (**17**) becomes

$$a_n = \frac{C}{2}\left[3\cos(\omega t - nD)\right]$$
$$- \frac{C}{2}\left[\cos(\omega t + nD) + \cos\left(\omega t + nD - \frac{2\pi y}{3}\right)\right.$$
$$\left. + \cos\left(\omega t + nD - \frac{4\pi y}{3}\right)\right] \quad (18)$$

Since y is always an integer but is never a multiple of 3, the last term equals zero and the expression becomes

$$a_n = \frac{3C}{2}\cos(\omega t - nD) \quad (19)$$

Similarly, when

$$-\frac{y}{6} - \frac{y n}{3P} = K_1$$

it follows that

$$a_n = \frac{3C}{2}\cos(\omega t + nD) \quad (20)$$

Suppose that neither of the foregoing assumptions is true. That is, $\left(-\frac{y}{6} \pm \frac{y n}{3P}\right)$ is not equal to an integer. It has been shown that in order for the nth harmonic to exist in the m. m. f. wave of a single phase,

$$\frac{n + \frac{p}{2}}{P/y} \text{ must equal } K_1$$

That is,

$$n = \frac{K_1 P}{y} - \frac{P}{2}$$

Substituting this value of n in the expression

$$-\frac{y}{6} \pm \frac{y n}{3P}$$

we obtain $\frac{K_1 - y}{3}$ when the plus sign is used and $\frac{K_1}{3}$ when the minus sign is used. When these values, neither of which is an integer, are substituted in equation (**17**), both terms become zero.

The criteria for the existence of the nth harmonic in the final wave are, then,
first,

$$\left(\frac{n + \frac{P}{2}}{P/y}\right) \text{ must equal } K_1, \quad (21)$$

and second,

$$\left(-\frac{y}{6} \pm \frac{y n}{3P}\right) \text{ must equal } K_2,$$

which may be written

$$\frac{y(P \pm 2n)}{6P} \text{ must equal } K_2 \quad (22)$$

where K_1 and K_2 are integers, including zero.

When the negative sign is used, the equation for the m. m. f. is

$$a_n = \frac{3\,C}{2} \cos(\omega t + n D) \tag{20}$$

When the positive sign is used,

$$a_n = \frac{3\,C}{2} \cos(\omega t - n D) \tag{19}$$

Substituting the values of C and D, the equations become

$$a_n = \frac{0.95\,M\,P}{n\,y} \sqrt{1 - \cos n\beta}\,\cos(\omega t + n\alpha - n\theta_n - n\psi) \tag{23}$$

and

$$a_n = \frac{0.95\,M\,P}{n\,y} \sqrt{1 - \cos n\beta}\,\cos(\omega t - n\alpha + n\theta_n + n\psi) \tag{24}$$

These expressions represent waves of constant magnitude which glide around the armature at speeds equal to one wavelength per cycle of current. Equation (**23**) is a wave traveling in one direction while (**24**) is a wave with opposite rotation. If n is made equal to $\frac{P}{2}$, the expression $\frac{y(P \pm 2n)}{6P}$ becomes an integer (zero in this case) when the minus sign is used. That is, equation (**20**) represents the m. m. f. wave. Since a value of n equal to $\frac{P}{2}$ corresponds to the synchronous component of the m. m. f., it follows that for those cases in which the minus sign is used to satisfy the equation

$$\frac{y(P \pm 2n)}{6P} = K_2$$

the wave travels with rotation. When the positive sign is used the wave moves opposite to the direction of the rotor.

Reactive Voltages. Let a_n' equal the maximum ordinate of the nth harmonic m. m. f. wave. Then,

$$a_n' = \frac{0.95\,M\,P}{n\,y} \sqrt{1 - \cos n\beta}$$

The flux density at any point, assuming a constant permeance, p, is

$$B_n = a_n'\,p \cos[\omega t + n\alpha - n\theta_n - n\psi] \tag{25}$$

for a positively rotating wave.

The flux enclosed by the reference coil is

$$\Phi_n = a_n'\,p\,N \int_0^\beta \cos[\omega t + n\alpha - n\theta_n - n\psi]\,d\alpha \tag{26}$$

where N is a constant equal to the surface of the armature divided by 2π.

Integrating,

$$\Phi_n = \frac{a_n'}{n}\,p\,N\,[\sin(\omega t + n\beta - n\theta_n - n\psi) - \sin(\omega t - n\theta_n - n\psi)] \tag{27}$$

The voltage induced in the coil is

$$e_n = -10^{-8}\frac{d\,\Phi_n}{d\,t} \tag{28}$$

Differentiating,

$$e_n = \frac{a_n'\,p\,N\,\omega}{n\,10^8}[\cos(\omega t + n\beta - n\theta_n - n\psi) - \cos(\omega t - n\theta_n - n\psi)] \tag{29}$$

which reduces to,

$$e_n = \frac{2\,a_n'\,p\,N\,\omega}{n\,10^8} \sin\frac{n\beta}{2} \sin\left(\frac{n\beta}{2} + \omega t - n\theta_n - n\psi - \pi\right) \tag{30}$$

The voltage per phase is found by adding vectorially the voltages of the individual coils. But the time angle between the voltages of any two coils is the same as the space angle between their m. m. f. waves. We can make use of the previous vector addition, therefore, and write the expression for the voltage per phase:

$$E_n = \frac{e_n\,M\,P}{y} \tag{31}$$

which is a voltage wave displaced from the voltage of the reference coil by the angle $n\psi$. Thus the complete expression for the phase voltage is

$$E_n = \frac{2\,a_n'\,p\,N\,\omega\,M\,P}{n\,y\,10^8} \sin\frac{n\beta}{2} \sin\left(\frac{n\beta}{2} + \omega t - n\theta_n - 2n\psi - \pi\right) \tag{32}$$

Substituting the value of a_n',

$$E_n = \frac{2.68\,p\,N\,\omega\,M^2\,P^2}{n^2\,y^2\,10^8} \sin^2\frac{n\beta}{2} \sin\left(\frac{n\beta}{2} + \omega t - n\theta_n - 2n\psi - \pi\right) \tag{33}$$

It will be convenient, usually, to express the reactance voltage in per cent of normal voltage. If $a_n'\,p$ is expressed as a percentage of normal flux we may write,

from equation (**32**), the expression for reactance voltage due to the nth harmonic as,

$$\% E_n = \frac{(a_n'\, p)\, N_s\, M_n \sin \frac{n\,\beta}{2}}{N\, M_s \sin \frac{n_s\,\beta}{2}}$$

$$\sin\left(\frac{n\,\beta}{2} + \omega\, t - n\,\theta_n - 2\,n\,\psi - \pi\right) \qquad (\mathbf{34})$$

where N_s and M_s correspond to the synchronous harmonic.

Equation (**34**) gives the reactance voltage per phase due to the flux set up by any one harmonic in the armature m. m. f. It will be seen that the phase position of this voltage varies with the order of the harmonic. To find the total reactance voltage due to m. m. f. harmonics it is necessary to solve for each component voltage and then add all components in proper angular relation.

List of Symbols

α = distance along the armature in radian measure
a = ordinate of m. m. f. wave
a' = maximum ordinate of resultant m. m. f. wave
β = coil throw in radians
B = flux density

$$C = \frac{0.636\, M\, P}{n\, y} \sqrt{1 - \cos n\,\beta}$$

$D = (\alpha - \theta_n - \psi)$
e = reactance voltage of single coil
E = reactance voltage of one phase
f = frequency
K = an integer
M = ratio of resultant vector to single vector
n = order of harmonic
N = constant depending on machine dimensions
p = permeance
P = number of poles
S = slot pitch in angular measure
t = time in seconds
$\omega = 2\,\pi\, f$
y = denominator of fraction equal to slots per pole
θ = displacement of wave from the origin
ϕ = angular position of any coil
ψ = angle between resultant vector and zero vector.

Country roads should be lighted. They should be lighted by a system that will cost $500 or $600 a mile. Then travel will be heavier and safer, according to a committee of the Empire State Gas and Electric Association which has just made a report on the subject. Farmers should back the plan, says the committee, because it will help to extend electric light and power lines so as to put electric service within reach of more farms.

POWER DEVELOPMENT IN SWITZERLAND

One of the natural resources with which Switzerland is well endowed, says Commerce Reports, is water power making it to a large degree free from dependence on foreign countries for fuel. The high price of coal during the war turned attention to new uses for electricity, especially in households. Consumption for heating as well as lighting and cooking was increased and the basis was laid for a much wider use of electricity.

During 1914 the capacity of hydroelectric plants totaled 526,000 h. p., and at present it is 1,850,000 h. p. Furthermore, plants which will furnish 280,000 h. p. are under construction, and about 1,000,000 h. p. more is projected. Important developments temporarily discontinued include the Nord-Ost-Schweizerische-Kraftwerke, a low head plant on the Aar River, near Bottstein, and a reservoir in the Urseren Valley which was to serve the region around Ruess. In the Berne region, the upper dam on the Oberhasli will be carried to completion. These operations will make available 100,000 horse power. The only large new hydroelectric work carried to a conclusion since 1921 is that at Waggital which brought in 140,000 h. p. on January 4, 1926. Other plans for construction include Chancy-Pougny, Illsee-Tourtemagne, and Davos-Klosters. In 1913 the capacity of existing power plants amounted to 0.23 h. p. per inhabitant; at the close of 1925 it amounted to 0.47 h. p. Now almost every locality is supplied with electricity, and the electric network covers a large portion of the total area.

The production by private enterprises from 1916 to 1924, as compared with the total production, increased 16.6 per cent; that of concerns owned partly by local governmental bodies and partly by private individuals decreased 11.2 per cent; and that of purely governmental enterprises decreased 10.4 per cent. The share of the Swiss Federated Railways was 5 per cent of the total production in 1924, and was increased considerably when the Barberine Plant was started. Private enterprises have developed much more rapidly than public enterprises.

Much more attention is now being paid to the building or enlargement of plants to meet the fluctuations which exist in summer and winter consumption. As a rule, the energy available is insufficient in the winter months but more than sufficient in the summer. To offset difficulties of this sort artificial or natural lakes are being drawn upon to establish an equilibrium and other supplementary sources of water supply are being created.

Swiss electrical development in recent years has tended toward the elimination of many small plants in favor of a few large ones. At the beginning of 1925 there were 46 hydroelectric plants in the country capable of generating more than 10,000 horse power each. The installed horse power of these totaled 1,194,410. The largest establishment at the beginning of 1925 was the Lubtsch Plant in the Canton of Claria.

Design of Reactances and Transformers
Which Carry Direct Current

BY C. R. HANNA[1]

Associate, A. I. E. E.

Synopsis.—It is usually necessary to place an air-gap in the core of a reactance or transformer which carries direct current in order to secure the greatest inductance. The work here reported points out a direct method of designing such reactances or transformers including the determination of the best value of the air-gap.

* * * * *

Introduction

THE design of reactances or transformers in which considerable direct current flows is a problem of increasing importance. Interstage and output transformers for vacuum tube amplifiers, modulator chokes for radio-telephone transmitters, and reactances for rectifier filter circuits are examples. In all of these a high value of a-c. inductance is required, but the saturating effect of the direct current always causes the inductance to be lower than if it were not flowing. It is well known that in every such case an increase of inductance will result if an air-gap is introduced in the magnetic circuit. Where the steady m. m. f. is high, the best air-gap will be large; where it is low the best air-gap will be small, sometimes small enough so that the air spaces in the stacking of the core laminations are sufficient.

So far as the writer is aware, no direct method of predetermining this best air-gap has been presented. The usual method is to assemble a reactance or transformer and determine experimentally the best gap. The inductance for this best gap usually does not come to the required value, and a re-design is necessary. After several attempts, of course, the correct design can be determined, but a direct method of design is greatly to be desired.

The purpose of this paper is to set forth a straightforward method of solving this problem.

Method of Calculation

Use is made of the permeability curves, both normal and incremental, for the core material used. As an example, the calculation will be carried through for four per cent silicon steel. Curves of Fig. 1 show the normal and incremental permeability for different values of B. Incremental permeability values are for very small minor loops, and were calculated from information given in a paper by Spooner[2]. Values for very small loops are used because in many cases the requirements are that the inductance shall be equal to, or greater than, a certain value for any applied alternating voltage, no matter how small, and it is well known that the incremental permeability (and therefore the inductance), is smallest when the flux variations are small. Examples are the modulator choke in a radio-telephone transmitter, interstage and output transformers in audio amplifiers, etc. In the case of reactors for filter circuits where the pulsations are always large, advantage can be taken of the larger incremental permeability corresponding to the greater flux variations. The calculations here given do not include this case, but may serve as a guide in the design of such reactances. The magnitude of the flux variations must be known or determinable for such calculations.

The following notation will be used:

B = Steady flux density in iron and air-gap, gausses.
N = Number of turns in winding.
I = Direct current, amperes.
A = Area of core section and air-gap, cm.^{2}
l = Length of iron path, cm.
a = Air-gap length, cm.
L = A-c. inductance, henries.

μ = Normal permeability $= \dfrac{B}{H}$

μ_Δ = Incremental permeability $= \dfrac{\Delta\ B}{\Delta\ H}$ where ΔB and ΔH are the increments from tip to tip of a minor hysteresis loop.

We have

$$B = \frac{0.4\,\pi\,N\,I}{\dfrac{l}{\mu} + a} \tag{1}$$

and

$$L = \frac{0.4\,\pi\,N^2\,A \times 10^{-8}}{\dfrac{l}{\mu_\Delta} + a} \tag{2}$$

From (1)

$$N = \frac{B\left(\dfrac{l}{\mu} + a\right)}{0.4\,\pi\,I} \tag{3}$$

1. Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.
2. T. Spooner, "Effect of a Superposed Alternating Field on Apparent Magnetic Permeability and Hysteresis Loss," *Physical Review*, 1925.

To be presented at the Winter Convention of the A. I. E. E., New York, N. Y., February 7-11, 1927.

Substituting in (**2**)

$$L = \frac{B^2 \left(\frac{l}{\mu} + a \right)^2 A \times 10^{-8}}{0.4\, \pi\, I^2 \left(\frac{l}{\mu_\triangle} + a \right)}$$

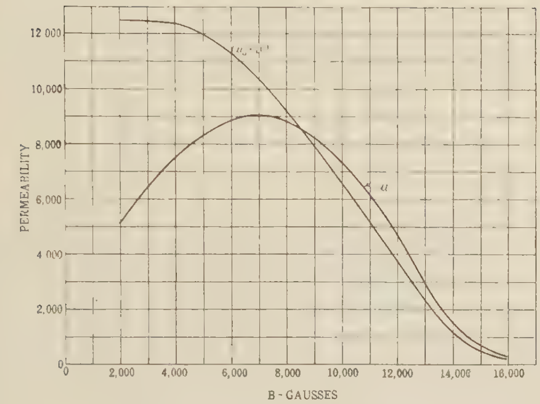


FIG. 1—NORMAL AND INCREMENTAL PERMEABILITY FOR 4 PER CENT SILICON STEEL

$$= \frac{B^2 \left(\frac{1}{\mu} + \frac{a}{l} \right)^2 l\, A \times 10^{-8}}{0.4\, \pi\, I^2 \left(\frac{1}{\mu_\triangle} + \frac{a}{l} \right)} \tag{4}$$

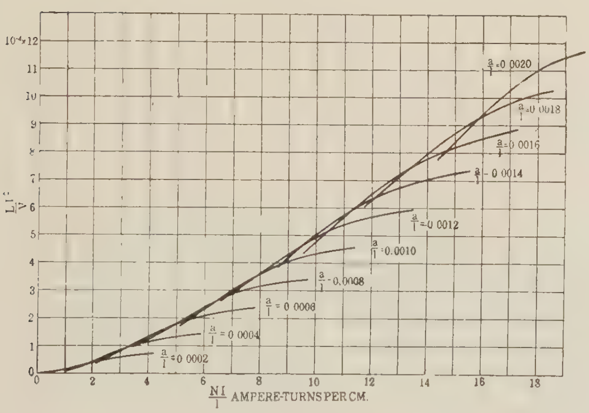


FIG. 2—4 PER CENT SILICON STEEL

Letting $l\,A = V$, the volume of iron in the core,

$$\frac{L\, I^2}{V} = \frac{B^2 \left(\frac{1}{\mu} + \frac{a}{l} \right)^2 \times 10^{-8}}{0.4\, \pi \left(\frac{1}{\mu_\triangle} + \frac{a}{l} \right)} \tag{5}$$

Also from (**1**)

$$\frac{N\ I}{l} = \frac{B}{0.4\, \pi} \left(\frac{1}{\mu} + \frac{a}{l} \right) \tag{6}$$

For any assigned value of $\frac{a}{l}$ (the per cent air-gap) equations (**5**) and (**6**) may be considered as parametric equations with B as the parameter, and a curve of $\frac{L\, I^2}{V}$ against $\frac{N\ I}{l}$ can be plotted. To do this, several values of B are assigned, and the values of μ

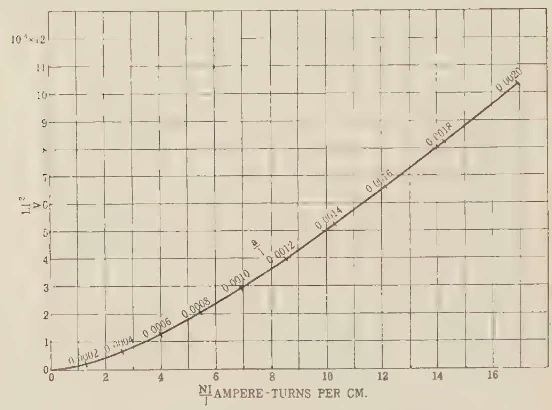


FIG. 3—4 PER CENT SILICON STEEL

and $\mu_\triangle$ corresponding to B obtained from curves of Fig. 1. These values are substituted in equations (**5**) and (**6**) to determine corresponding values of $\frac{L\, I^2}{V}$ and $\frac{N\ I}{l}$. $\frac{N\ I}{l}$ represents the steady ampere turns for each centimeter of iron length and $\frac{L\, I^2}{V}$ is

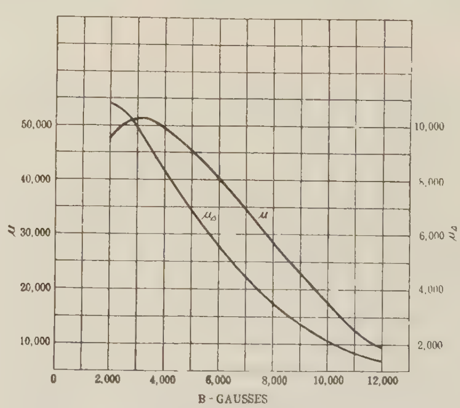


FIG. 4—NORMAL AND INCREMENTAL PERMEABILITY CURBES FOR HYPERNIK

a quantity which if divided by the square of the current gives the inductance per cm.[3] of core.

The family of curves, each for a different value of $\frac{a}{l}$, is shown in Fig. 2. It is seen that if $\frac{N\ I}{l}$ is increased, by increasing N or I or by reducing l, $\frac{L\, I^2}{V}$

is greater for larger values of $\frac{a}{l}$. Evidently the envelope of the family of curves gives the relation between $\frac{L\,I^2}{V}$ and $\frac{N\;I}{l}$ if the best value of $\frac{a}{l}$ is chosen. Since each curve of the family corresponds to a certain value of $\frac{a}{l}$, the point of tangency with the envelope shows the value of $\frac{N\;I}{l}$ that requires this $\frac{a}{l}$. Hence along the envelope curve may be plotted a scale which shows the proper value of $\frac{a}{l}$. Fig. 3 shows the envelope curve with the $\frac{a}{l}$ scale along it.

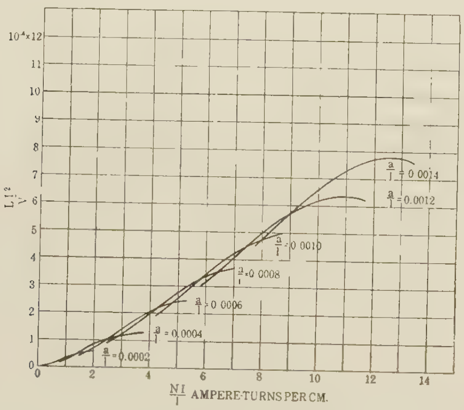


Fig. 5—Hypernik

Using this curve, it is quite simple to design reactances. Suppose a certain core size is chosen and a winding and air-gap are to be determined such that when a direct current I flows in the winding, the a-c. inductance will be L. The value of $\frac{L\,I^2}{V}$ is thus determined, and the corresponding value of $\frac{N\;I}{l}$ can be obtained from the curve. The core length l and the current I being known, N is determined. The value of $\frac{a}{l}$ can also be read from the curve, and thus the proper air-gap is determined.

To illustrate with a specific example, suppose

l = 14 cm.
A = 5.5 cm.²
L = 12 henrys
I = 0.05 amperes

then

$$\frac{L\,I^2}{V} = \frac{12 \times 0.05^2}{14 \times 5.5} = 3.9 \times 10^{-4}$$

From curve

$$\frac{N\;I}{l} = 8.43$$

$$N = \frac{8.43 \times 14}{0.05} = 2360$$

Also

$$\frac{a}{l} = 0.0012 \qquad a = 0.0168 \text{ cm.}$$

It may be that to obtain the 2360 turns in the given winding space the resistance will be too high. Where this is the case, a larger sized punching or perhaps more punchings of the same size should be used, so as to increase the iron section. The calculation should be carried through again in the same way, a few trials usually being sufficient.

It frequently happens that the greatest inductance possible is desired for a given core size. If I has a definite value as before, it is readily seen from the curve that the greater the number of turns the greater the inductance for a given volume of iron, provided the air-gap is increased as shown by the curve. Hence a coil with the greatest possible number of turns as determined by the permissible resistance or capacity of the winding should be employed.

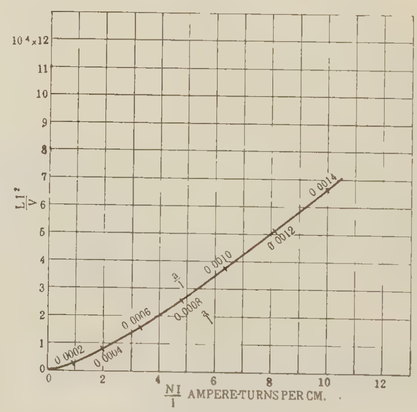


Fig. 6—Hypernik

For example, suppose with the core given in the first example, 4000 turns could be wound without exceeding the limiting value of resistance. If the current is as before

$$\frac{N\;I}{l} = \frac{4000 \times 0.05}{14} = 14.3$$

From the curve

$$\frac{L\,I^2}{V} = 8.2 \times 10^{-4}$$

from which

$$L = \frac{8.2 \times 10^{-4} \times 14 \times 5.5}{(0.05)^2} = 25.2 \text{ henries.}$$

The value of $\frac{a}{l}$ to obtain this is 0.0018. Therefore $a = 0.0018 \times 14 = 0.025$ cm.

The same calculation has been carried through for 50 per cent nickle iron. Curves of Fig. 4 show the normal and incremental permeability, the latter having

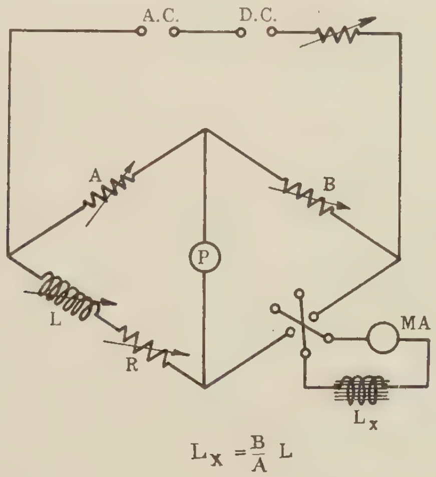


Fig. 7—A-c. Bridge

been calculated as before. The family of curves of $\frac{L\,I^2}{V}$ against $\frac{N\ I}{l}$ for different percentages of air-gap is shown in Fig. 5. Fig. 6 shows the envelope of this family with the scale of best $\frac{a}{l}$ values plotted along it.

The curves for both silicon and nickle iron have been used in the design of reactances and transformers and have been found accurate to a surprising degree when annealed punchings were employed. Inductance values were within 15 per cent of the calculated values. The best air-gap, not being critical, was always close enough so that no change from the calculated value was necessary.

Alternate Method of Determining Curves

It is seen readily that the curves may be determined from experimental data instead of by computation. Each curve of the family is the relation of $\frac{L\,I^2}{V}$ against $\frac{N\ I}{l}$ for a given value of $\frac{a}{l}$. If a core of uniform section is secured and a winding placed on it, its a-c. inductance for different values of direct current may be measured by means of an a-c. bridge as shown in Fig. 7. Holding the air-gap fixed, the data for one curve of $\frac{L\,I^2}{V}$ against $\frac{N\ I}{l}$ can be determined. The air-gap may then be changed and another set of data obtained, and so on until the whole family of curves is determined. Then the envelope with its $\frac{a}{l}$ scale may be drawn.

Fig. 8 shows two curves of the family for 50 per cent nickle steel that were determined in this way. The

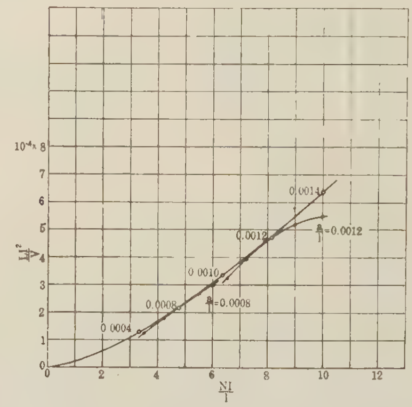


Fig. 8—Experimental Curve for Hypernik

envelope is also shown and is found to agree fairly closely with the calculated envelope of Fig. 6.

In using the bridge, the direct current in the choke or transformer is varied by the resistance in series with the supply. A reversing switch is used to make sure that the induction in the core is that corresponding to the normal B-H curve. Small values of a-c. voltage are employed.

This method is best adapted to cases where the normal and incremental permeability values for the material are not available.

A PORTABLE RADIO DIRECTION FINDER

The Bureau of Standards has just issued a paper by F. W. Dunmore, which describes the development of a portable radio direction finder with but two controls—one for tuning and one for balancing. This direction finder operates over the frequency band from 90 to 7700 kilocycles (3300 to 39 meters). The direction finder is of the simple rotating coil type. The receiving set is of the superheterodyne type, with the controls reduced to one by the use of a cam-operated condenser. The wide frequency range is made possible by a set of seven interchangeable plug-in direction finder coils, each with a corresponding heterodyne generator coil and cam for operating the auxiliary tuning condensers.

This paper is obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 10 cents per copy.

Maxwell's Theory of the Layer Dielectric

BY FRANCIS D. MURNAGHAN[1]

Non-member

(with an Introduction by J. B. Whitehead)

Synopsis.—*Maxwell stated in his "Electricity and Magnetism" that for a non-homogeneous dielectric built up of n plane layers of varying thicknesses and varying ratios of resistivity to specific capacity, the charging current will be given by a linear differential equation of order n-1 involving the nth derivative of the applied e. m. f. This equation and its detailed solution are given here and the two cases of greatest practical interest,—namely the case where the applied e. m. f. is constant and the case where it is a pure harmonic,—are treated fully. By a Fourier analysis the general case can be reduced to these two.*

Introduction

The phenomenon of dielectric absorption has recently attracted renewed interest by reason of its importance in problems of the insulation of high voltage electrical circuits. It is recognized that absorption causes energy losses in the body of the insulation; these losses increase the temperature, leading to deterioration and final failure of the insulation.

No completely satisfactory theory of the nature of dielectric absorption has been proposed. In recent years a number have been offered invoking newly discovered physical phenomena in the fields of gaseous ionization, dissociation, and conductivity in liquids, and the electromechanics of atomic structure. These theories, for the most part, however, are mere speculations and none of them is subject to exact experimental test. The earliest theory proposed to account for dielectric absorption is that of Clerk Maxwell. It shares with all other theories the disadvantage that it has never been satisfactorily supported by experiment. It has nevertheless maintained its position as the most satisfactory theory yet offered, largely because it invokes only well recognized properties of dielectrics, namely, specific inductive capacity and conductivity, and makes no appeal to new properties nor any molecular nor sub-atomic phenomena.

All students of dielectric theory are familiar with Maxwell's treatment. He assumes a dielectric built up of a number of plane strata of different materials, stating that a medium formed of a conglomeration of small pieces of different materials would behave in the same way. He does not support this latter statement by further analysis, however. The most familiar manifestation of absorption is a sustained but continuously decreasing current when a continuous electromotive force is applied to a condenser having a solid dielectric. The same type of phenomenon occurs when the condenser is discharged. In this case it is the outflow of the familiar residual charge of the condenser. In the case of Maxwell's layer condenser, the different values of the specific capacity and resistivity in successive layers accounts for the relatively long time necessary for complete charge or discharge.

Many experimental studies have aimed to determine the law governing the gradual decay of the charging current of a condenser. Some of these have indicated a simple negative power of the time, others an exponential relation, and still others more complicated relationships. Maxwell did not extend his analysis to the derivation of the form of the function controlling the decay of the charging current of a layer dielectric nor, apparently, has this extension ever been made, under his theory, for the completely general case. It may be readily shown, however, that for the case of two layers the charging current decreases in accordance with a simple exponential function of the time with negative exponent. It has been generally assumed by supporters of Maxwell's theory that in the general case of any number of layers, or of a dielectric consisting of a mixture of any number of different materials, the complex form of the charging current curve is due to the superposition of a number of separate exponential terms with negative exponents. This assumption is supported by Maxwell's statement that for n layers of materials having different values of the ratio of resistivity to specific capacity there will result for the charging current a differential equation of order $n - 1$, involving the nth order derivative of the applied electromotive force. Maxwell, however, does not derive the expression supporting this statement, and this omission has always constituted a difficulty for those seeking experimental means for testing the validity of his theory. Dr. Murnaghan has now supplied this deficiency and has derived in an elegant and satisfactory manner the expression for the charging current for the most general case of a layer dielectric. Equation (**14**) shows that this current is made up of a constant term, giving the final conduction current, plus $n - 1$ negative exponential terms of which the coefficients and constant parts of the exponents are given in terms of the constants of the various layers. This confirms Maxwell's statement and provides a ready means whereby one may use the convenient charging current as a basis for analysis and experimental check.

The extension of Maxwell's expressions to the alternating case has always involved great difficulty. Dr. Murnaghan has now made this extension in its most general form. His equations may be readily transformed to the simplest cases and they should offer

1. Johns Hopkins University.

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frequent and convenient opportunity for application to experimental problems.

The National Research Council, through its division of Engineering and Industrial Research, has organized a Committee on Electrical Insulation. This committee during the past two years has been making a review of the widely scattered literature on dielectric behavior, in an attempt to point out the direction in which experiment may be prosecuted with the best chance of profitable result. As a result of conversations with the writer in connection with this review, Dr. Murnaghan has been good enough to undertake the analysis which he now presents and to consent to its being offered under the auspices of the committee mentioned above. The committee also has in progress reviews of our present knowledge of dielectric behavior from the standpoints of resistivity and dielectric strength, and in connection with all these reviews it is proposing problems for experimental research. Of particular interest in connection with Dr. Murnaghan's paper is a series of experimental investigations now under way at Johns Hopkins University on the origin and nature of dielectric absorption, one of the first phases of which will be an attempt to test the validity of Maxwell's theory. The investigation was suggested by the work of the Committee on Electrical Insulation, N. R. C., and is receiving substantial financial support from the Engineering Foundation.

* * * * *

CONSIDERING unit cross-section of the plane strata of Maxwell's layer dielectric, let X_1, X_2, etc., be the electric intensities in the several strata; f_1, f_2, etc., the displacements; k_1, k_2, etc., the reciprocals of the specific inductive capacities; r_1, r_2, etc., the specific resistances. Then at any instant the conduction current in the first layer is X_1/r_1, while the displacement current in the same layer is $\frac{1}{4\pi k_1}\frac{dX_1}{dt}$, so that we have $u = (X_1/r_1) + (1/4\pi k_1)\, dX_1/dt$ where u is the current density in the outer circuit and so in each layer. Denoting the thicknesses of the various layers by a_1, a_2, etc., the e. m. f. across the first layer is $a_1 X_1$, that across the second layer is $a_2 X_2$, and so on for each layer. If there are altogether n layers, the total e. m. f. across the dielectric is connected with the various intensities by the relation

$$E = a_1 X_1 + a_2 X_2 + \ldots + a_n X_n \qquad (1)$$

It is more convenient to deal with the displacements f than with the electric intensities X; on introducing the abbreviations

$$4\pi k_1/r_1 = b_1;\ 4\pi k_2/r_2 = b_2;\ \ldots\ 4\pi k_n/r_n = b_n$$
$$4\pi k_1 a_1 = \alpha_1;\ 4\pi k_2 a_2 = \alpha_2;\ \ldots\ 4\pi k_n a_n = \alpha_n \quad (2)$$

the equations expressing the fact that the current density in each layer is the same, take the form

$$(D + b_1) f_1 = (D + b_2) f_2 = \ldots = (D + b_n) f_n = u \qquad (3)$$

where, for convenience, we have used the symbol D for the sign of differentiation d/dt. Also equation (1) takes the form

$$\alpha_1 f_1 + \alpha_2 f_2 + \ldots + \alpha_n f_n = E \qquad (4)$$

Solving for one of the displacements, say f_1, from (4) we have

$$\alpha_1 f_1 = E - \alpha_2 f_2 - \ldots - \alpha_n f_n$$

and on substituting this in the equation $(D + b_1) f_1 = (D + b_2) f_2$ we obtain

$$[(\alpha_1 + \alpha_2) D + (\alpha_1 b_2 + b_1 \alpha_2)] f_2 + \alpha_3 (D + b_1) f_3 + \ldots + \alpha_n (D + b_1) f_n = (D + b_1) E$$

In addition to this equation connecting the $n - 1$ displacements $(f_2, f_3, \ldots f_n)$ we have the $n - 2$ equations

$$(D + b_2) f_2 - (D + b_3) f_3 = 0$$
$$(D + b_2) f_2 - (D + b_4) f_4 = 0$$
$$\ldots\ldots\ldots$$
$$(D + b_2) f_2 - (D + b_n) f_n = 0$$

From the $n - 1$ equations now in our possession all but one of the displacements, say f_2, may be eliminated by the usual algebraic process. The determinant of the coefficients is quite simple; for convenience of writing let us take $n = 4$ although it will be quite obvious that the reasoning is general. The determinant of the coefficients being

$$\begin{vmatrix} (\alpha_1 + \alpha_2)D + (\alpha_1 b_2 + \alpha_2 b_1) & \alpha_3 (D + b_1) & \alpha_4 (D + b_1) \\ (D + b_2) & -(D + b_3) & 0 \\ (D + b_3) & 0 & -(D + b_4) \end{vmatrix}$$

we expand it in terms of its first row. The result is

$$\alpha_1(D+b_2)(D+b_3)(D+b_4)+\alpha_2(D+b_1)(D+b_3)(D+b_4)$$
$$+\alpha_3(D+b_1)(D+b_2)(D+b_4)+\alpha_4(D+b_1)(D+b_2)(D+b_3)$$

In the general case of n layers we may write the determinant of the coefficients of our equations conveniently in the form

$$(D + b_1)(D + b_2)\ldots(D + b_n)\left[\frac{\alpha_1}{D + b_1} + \frac{\alpha_2}{D + b_2} + \ldots + \frac{\alpha_n}{D + b_n}\right] \qquad (5)$$

This is a polynomial in the sign of differentiation D of degree $n - 1$, the coefficient of D^{n-1} being $(\alpha_1 + \alpha_2 + \ldots + \alpha_n)$. This sum of the α's occurs so frequently that it will be well to have a single symbol for it; denote it simply by α and write the determinant of the coefficients in the form $\alpha\,\varphi(D)$, so that $\varphi(D)$ is a polynomial of degree $n - 1$ in D, the coefficient of the highest power in D being unity. The equation for f_2 is, then,

$$\alpha\,\varphi(D) f_2 = (D + b_1)(D + b_3)\ldots(D + b_n) E$$

where the operator $(D + b_2)$ is missing from the product on the right. The equations for the other displace-

ments are similar; they may be conveniently written in the symbolical form

$$\left[\frac{\alpha_1}{D + b_1} + \frac{\alpha_2}{D + b_2} + \ldots + \frac{\alpha_n}{D + b_n}\right] f_r = \frac{E}{D + b_r} \qquad (6)$$

which means that the various denominators $(D + b)$ are first removed by multiplying through by the common denominator $(D + b_1)(D + b_2) \ldots (D + b_n)$. It follows at once from (6) and (3) that the current density u is given by the equation

$$\left[\frac{\alpha_1}{D + b_1} + \ldots + \frac{\alpha_n}{D + b_n}\right] u = E \qquad (7)$$

or, in non-symbolic form,

$$\alpha\,\varphi(D)\,u = (D + b_1)(D + b_2) \ldots (D + b_n)\,E \quad (8)$$

Equation (8) is the equation to which Maxwell referred but which he rather unfortunately neglected to give explicitly. There is every probability that he arrived at it by the following reasoning; we may write the equations (3) in the symbolic form

$$f_r = u/(D + b_r)$$

and on inserting these values in (4) we arrive immediately at (7).

The equations (6) and (8) are linear differential equations with constant coefficients and are of the order $n - 1$ provided all the ratios of capacity to resistivity for the various layers are different; it is apparent from the symmetrical form of the left-hand side of (6) that the order in which the layers are supposed arranged is of no importance and if two of the b's, b_1 and b_2 let us say, are equal, we may combine the first two terms $\alpha_1/(D + b_1)$ and $\alpha_2/(D + b_2)$ of the left-hand side of (6) into the single term $(\alpha_1 + \alpha_2)/(D + b_2)$ and imagine that instead of the two layers 1 and 2 we have a single equivalent layer whose α is the sum of the two α's of the layers which it replaces. We shall suppose from this on, therefore, that all the b's are different. We shall also find it more convenient to consider the equations (6) rather than the equation (8) for the current density to which Maxwell called attention, the reason being that a determinate solution of a differential equation is not possible unless some information, such as the initial value of the unknown and its various derivatives, is at hand. Now the initial values of the displacements were shown by Maxwell to be all equal, the dielectric being supposed initially uncharged, his reasoning being as follows. From (3) we have, on integrating with respect to the time from 0 to Δt, results such as

$$\Delta f_1 + \int_0^{\Delta t} b_1 f_1\, d\,t = \Delta f_2 + \int_0^{\Delta t} b_2 f_2\, d\,t$$

each side being equal to the charge per unit area $\int_0^{\Delta t} u\, d\,t$ which flows through the dielectric in time Δt. If we let the time interval Δt tend to zero and assume that the displacements f remain finite during the sudden imposition of an e. m. f., we have the limiting equation $\Delta f_1 = \Delta f_2$, and if f_1 and f_2 were zero before the e. m. f. was applied this says that their initial values, *i. e.*, the values immediately after the imposition of the e. m. f., will be equal. If $E(0)$ denotes the initial value of the applied e. m. f., we find from (4) that the common initial value of the displacements is

$$f_0 = E(0)/\alpha \qquad (9)$$

where

$$\alpha = \alpha_1 + \alpha_2 + \ldots + \alpha_n \qquad (10)$$

We now proceed to solve the equations (6) in the particular case where a constant e. m. f. of amount unity is applied at time $t = 0$ to the uncharged dielectric, the initial values of the displacements f being accordingly $1/\alpha$. A possible solution of (6) in this case where $E = 1$ may be found by giving f_r the constant value $1/b_r\,(\sum_r \alpha_r/b_r)$ but this is not the solution of the problem before us since it does not give all the f's the same initial value. The difference between this value of f_r and the solution we need, however, will satisfy the homogeneous equation

$$\left[\frac{\alpha_1}{D + b_1} + \ldots + \frac{\alpha_n}{D + b_n}\right] f_r = 0,$$

$$i.\,e., \qquad \alpha\,\varphi(D)\,f_r = 0 \qquad (11)$$

which, being a linear homogeneous differential equation with constant coefficients of order $n - 1$, has for its general solution a combination of $n - 1$ exponential functions of the time with arbitrary constant multipliers. To determine the exponents of the exponential functions we observe that since $\varphi(D)$ is a sum of n terms each of which has all the $(D + b_r)$ but one as a factor the value of $\varphi(-b_r)$ is $\alpha_r(b_1 - b_r)(b_2 - b_r) \ldots (b_n - b_r)/\alpha$. Now let us suppose the quantities $(b_1, b_2, \ldots b_n)$ arranged in ascending order of magnitude; then $\varphi(-b_1)$ *will* be positive since all its factors are positive but $\varphi(-b_2)$ will be negative since one of its factors, $(b_1 - b_2)$, is negative. $\varphi(-b_3)$ will be positive since two of its factors are negative, and so on. This tells us that the polynomial φ of degree $n - 1$ has all its zeros real and negative and that they lie in the intervals between the negative values of the b's. Let us denote these zeros by $(-\beta_1, -\beta_2, \ldots -\beta_{n-1})$ where the β's are supposed arranged in ascending order of magnitude. We have, then, the series of inequalities,

$$b_1 < \beta_1 < b_2 < \beta_2 < \ldots < b_{n-1} < \beta_{n-1} < b_n \qquad (12)$$

and the most general solution of (11) is a linear combination with constant coefficients of the exponential

functions $\epsilon^{-\beta_1 t}$, $\epsilon^{-\beta_2 t}$ . . . $\epsilon^{-\beta_{n-1} t}$. Remembering the relation $(D + b_r) f_r = (D + b_s) f_s$ connecting any two of the f's and noting that $D (\epsilon^{-\beta_r t}) = - \beta_r \epsilon^{-\beta_r t}$, we write the general solution of (**11**) in the form

$$\frac{A_1}{(b_r - \beta_1)} \epsilon^{-\beta_1 t} + \ldots + \frac{A_{n-1}}{(b_r - \beta_{n-1})} \epsilon^{-\beta_{n-1} t}.$$

In other words, the most general solution of the equations (**6**) (with $E = 1$), which obeys the relations (**3**) is

$$f_r = \frac{1}{b_r \sum_r (\alpha_r / b_r)} + \frac{A_1}{(b_r - \beta_1)} \epsilon^{-\beta_1 t} + \ldots + \frac{A_{n-1}}{(b_r - \beta_{n-1})} \epsilon^{-\beta_{n-1} t} \qquad (\mathbf{13})$$

where the A's are arbitrary constants. All that is necessary to complete the solution is to so determine the values of these constants that the f's may all assume initially the common value $1/\alpha$. Before proceeding to do this we may remark that it follows at once from (**3**) and (**13**) that the current density u is given by the expression

$$u = 1/(\sum_r (\alpha_r / b_r) + A_1 \epsilon^{-\beta_1 t} + \ldots + A_{n-1} \epsilon^{-\beta_{n-1} t} \qquad (\mathbf{14})$$

where the A's have the numerical values we are about to determine. The first term in this expression is the value to which u tends as t increases indefinitely and gives what is known as the permanent or conduction current.

The equations which determine the numerical values of the A's are found by putting $f_r = 1/\alpha$ and $t = 0$ in (**13**). They are

$$A_1/(b_r - \beta_1) + A_2/(b_r - \beta_2) + \ldots + A_{n-1}/(b_r - \beta_{n-1}) = 1/\alpha - 1/\alpha_r (\sum_r \alpha_r / b_r) \qquad (\mathbf{15})$$

where r is to be assigned, in turn, the values $(1, 2, 3, \ldots n)$ so that there are n equations in all. As there are only $n - 1$ A's to be found, these equations cannot be independent of one another; in fact if we multiply the equation written above by α_r and add all the results obtained by giving r the values 1 to n, both sides of the total vanish identically, showing that a set of A's satisfying $n - 1$ of the equations will satisfy the equation remaining. We may confine our attention, therefore, to the first $n - 1$ of the equations (**15**). A direct solution of these $n - 1$ equations would not be very elegant, however, on account of the lack of symmetry involved in the omission of one of the equations and it is better to proceed as follows:

Consider the quotient of the two polynomials of degree n

$$(x + b_1)(x + b_2) \ldots (x + b_n)/x \phi(x)$$

where $\varphi(x)$ is the function defined by the statement that $\alpha \varphi(D)$ is the expression (**5**). This quotient can be written in the form $1 + \frac{g(x)}{x \varphi(x)}$ where $g(x) = (x + b_1) \ldots (x + b_n) - x \varphi(x)$ is a polynomial of degree less than n. From its very definition the quotient $g(x)/x \varphi(x)$ has the value -1 when x is assigned any one of the n values $(-b_1, -b_2, \ldots - b_n)$ and, furthermore, since the zeros of φ are the $n - 1$ numbers $-\beta_r$, we have $g(-\beta_r) = (b_1 - \beta_r)(b_2 - \beta_r) \ldots (b_n - \beta_r)$. Now the usual method of analysis of the quotient of two polynomials into a series of simple fractions[2] tells us that

$$\frac{g(x)}{x \varphi(x)} = \frac{g(0)}{x \varphi(0)} + \sum_r \frac{g(-\beta_r)}{-\beta_r \varphi'(-\beta_r)(x + \beta_r)}$$

where $\varphi'(x)$ denotes the derivative of $\varphi(x)$ with respect to x. Giving x the n values $-b_s$, in turn, we have the n equations

$$-\sum_r \frac{g(-\beta_r)}{\beta_r \varphi'(-\beta_r)(b_s - \beta_r)} = 1 - g(0)/b_s \varphi(0);$$

$$s = 1, 2, \ldots n. \qquad (\mathbf{16})$$

Now $g(0)$ has the value $b_1 b_2 \ldots b_n$ and $\varphi(0)$ has the value $b_1 b_2 \ldots b_n [\sum_r (\alpha_r / b_r)]/\alpha$, so that $g(0)/\varphi(0)$ has the value $\alpha / \sum_r (\alpha_r / b_r)$. On substituting this in (**16**) and comparing the result with (**15**) we see that the desired values of the A's are furnished by the formulas

$$A_r = -\frac{1}{\alpha} \left[\frac{g(-\beta_r)}{\beta_r \varphi'(-\beta_r)} \right]$$

$$= -(b_1 - \beta_r)(b_2 - \beta_r) \ldots (b_n - \beta_r)/\alpha \beta_r \varphi'(-\beta_r) \qquad (\mathbf{17})$$

Since

$$\varphi(x) = \frac{1}{\alpha}(x + b_1)(x + b_2) \ldots (x + b_n) \left[\frac{\alpha_1}{x + b_1} + \ldots + \frac{\alpha_n}{x + b_n} \right]$$

and since the factor in square brackets vanishes when $x = -\beta_r$, we have

$$\varphi'(-\beta_r) = -\frac{1}{\alpha}(b_1 - \beta_r) \ldots (b_n - \beta_r) \left[\frac{\alpha_1}{(b_1 - \beta_r)^2} + \ldots + \frac{\alpha_n}{(b_n - \beta_r)^2} \right]$$

so that

$$A_r = \frac{1}{\alpha \beta_r \left[\frac{\alpha_1}{(b_1 - \beta_r)^2} + \ldots + \frac{\alpha_n}{(b_n - \beta_r)^2} \right]} \qquad (\mathbf{17}^{bis})$$

2. See note at end of paper.

This form is not particularly suited for purposes of calculation but it has the advantage of showing that all the constants A_r are positive. The expression for the initial value of the current, *i. e.*,

$$\frac{1}{\sum_r \frac{\alpha_r}{b_r}} + A_1 + A_2 + \ldots + A_{n-1}$$

follows directly from the equations (**3**). Denoting initial values of the subscript zero, we have $(D\,f_1)_0 = u_0 - b_1 f_0; \ldots (D\,f_n)_0 = u_0 - b_n f_0$ and on substituting these in the equation $\sum \alpha_r\,(D\,f_r)_0 = (D\,E)_0$ obtained by differentiating (**4**) and then setting $t = 0$, we find

$$\alpha\, u_0 - (\sum_r \alpha_r\, b_r)\, f_0 = (D\,E)_0$$

so that

$$u_0 = \frac{(D\,E)_0}{\alpha} + \frac{(\sum_r \alpha_r b_r)\, E\,(0)}{\alpha^2} \text{ by } (\mathbf{9})$$

In the case of a constant unit e. m. f. we have

$$u_0 = \frac{\sum_r \alpha_r\, b_r}{\alpha^2}$$

Upon substitution of the values given in (**17**) in the expressions (**13**) and (**14**), the displacements and current density at any instant are determined and the problem may be regarded as completely solved. We proceed to give an example of the method of procedure in the simple case of two layers.

When $n = 2$, $\varphi\,(D)$ is the simple linear expression $D + (\alpha_1\, b_2 + \alpha_2\, b_1)/\alpha$. Hence there is only one exponential term and the value of β_1 is

$$\beta_1 = (\alpha_1\, b_2 + \alpha_2\, b_1)/(\alpha_1 + \alpha_2) \qquad (\mathbf{18})$$

It is rather noteworthy that when the thickness of one of the layers gets very small so that α_1, say, tends to zero, the value of β_1 tends to the definite limit b_1. For numerical calculations it is well to express β_1 *directly* in terms of the capacities and conductivities of the layers. In Wagner's notation[3] we have $b_1 = 4\,\pi\, k_1\, \lambda_1 = \gamma\, \lambda_1/\epsilon_1$; $\alpha_1 = \gamma\, a_1/\epsilon_1$ where $\gamma = 36\,\pi\,.\,10^{11}$ is a constant depending on the choice of units. Hence β_1 has the form $\gamma\,(a_1\, \lambda_2 + a_2\, \lambda_1)/(a_1\, \epsilon_2 + a_2\, \epsilon_1)$; the reciprocal of β_1 measures the time taken for the transient part $A_1\, \epsilon^{-\beta_1 t}$ of the current to reduce to the fraction $1/\epsilon$ of its original value, and is called the time constant of the dielectric. For two equally thick layers the time constant has the expression

$$T = (\epsilon_1 + \epsilon_2)/\gamma\,(\lambda_1 + \lambda_2)$$

while in general if the second layer is m times as thick as the first one, $T = (m\,\epsilon_1 + \epsilon_2)/\gamma\,(m\,\lambda_1 + \lambda_2)$. For paper ϵ_1 may be taken around 2 while λ_1 is around 10^{-11} and for glass the values are around 8 and 10^{-15} respectively. If $m = 1$, so that the layers are equally thick, $T = 0.09$ sec., while if $m = 2$, so that the layer of glass is twice as thick as the layer of paper, $T = 0.05$ sec.; if $m = 1/2$ so that the layer of paper is twice as thick as the layer of glass, $T = 0.16$. The larger the ratio of the thickness of the paper to that of the glass the larger is the time constant, the theoretical limit when $m = 0$ being $\gamma\, \epsilon_2/\lambda_2$ which is about 700 sec.

The constant A_1 is given by (**17**); since $\varphi' = 1$ it is $(\beta_1 - b_1)\,(b_2 - \beta_1)/\alpha\,\beta_1$ which reduces to

$$A_1 = \alpha_1\, \alpha_2\, (b_2 - b_1)^2/(\alpha_1 + \alpha_2)^2\, (\alpha_1\, b_2 + \alpha_2\, b_1)$$
$$= a_1\, a_2\, (\lambda_2\, \epsilon_1 - \lambda_1\, \epsilon_2)^2/(a_1\, \epsilon_2 + a_2\, \epsilon_1)^2\, (a_1\, \lambda_2 + a_2\, \lambda_1)$$
$$= (\lambda_2\, \epsilon_1 - \lambda_1\, \epsilon_2)^2/(a_1\, \epsilon_2 + a_2\, \epsilon_1)^2 \left(\frac{\lambda_1}{a_1} + \frac{\lambda_2}{a_2} \right) (\mathbf{19})$$

It will be observed that if the thickness of one of the layers, say the first, tends to zero, A_1 also tends to zero on account of the term λ_1/a_1 in the denominator; if, however, λ_1 is very small in comparison with λ_2, it is possible that a_1 will be small in comparison with a_2 without the term λ_1/a_1 becoming significant.

In Wagner's notation, the constant term in the expression (**14**) for the current has the form $1/(\sum_r a_r/\lambda_r)$ which is, for the two-layer dielectric, $\lambda_1\, \lambda_2/(a_1\, \lambda_2 + a_2\, \lambda_1)$. The initial value of the current is $\dfrac{\alpha_1\, b_1 + \alpha_2\, b_2}{(\alpha_1 + \alpha_2)^2}$ or $\dfrac{(a_1\, \lambda_1\, \epsilon_2^2 + a_2\, \lambda_2\, \epsilon_1^2)}{(a_1\, \epsilon_2 + a_2\, \epsilon_1)^2}$; for the case of two layers of equal thickness d this is $\dfrac{\lambda_1\, \epsilon_2^2 + \lambda_2\, \epsilon_1^2}{d\,(\epsilon_1 + \epsilon_2)^2}$.

Section 2. The Alternating Case

Here we suppose an e. m. f. of the form $E = e^{\,i\omega t}$ applied at time $t = 0$. Since $(D + b_n)\, e^{\,i\omega t} = (i\,\omega + b_n)\, e^{\,i\omega t}$ and so on, our equations (**6**) for the various displacements take the form

$$\alpha\, \phi\,(D)\, f_r = \frac{(i\,\omega + b_1)\ \ldots\ (i\,\omega\, b_n)}{(i\,\omega + b_r)}\, e^{\,i\omega t}$$

A particular solution of these equations, which is consistent with the equations (**3**), is

$$f_r = \frac{B\, e^{i\omega t}}{i\,\omega + b_r} \qquad (\mathbf{20})$$

where the constant B is determined by the equation

$$\alpha\, \phi\,(i\,\omega)\, B = (i\,\omega + b_1)\ \ldots\ (i\,\omega + b_n) \qquad (\mathbf{21})$$

i. e.,

$$B = 1/\left[\frac{\alpha_1}{i\,\omega + b_1} + \frac{\alpha_2}{i\,\omega + b_2} + \ldots + \frac{\alpha_n}{i\,\omega + b_n}\right] \qquad (\mathbf{21}^{bis})$$

The general solution of the equations (**6**) is of the type

$$f_r = \frac{B\, e^{i\omega t}}{i\,\omega + b_r} + \frac{B_1\, e^{-\beta_1 t}}{b_r - \beta_1} + \ldots + \frac{B_{n-1}\, e^{-\beta_{n-1} t}}{b_r - \beta_{n-1}} \qquad (\mathbf{22})$$

3. See article in *Die Isolierstoffe der Electrotechnik* edited by Schering, H., pp. 1-59. Berlin, 1924.

where the factors β in the exponents are the same as before and the $(B_1, B_2, \ldots B_{n-1})$ are arbitrary constants. The values to be assigned to these must be such that the initial values of the displacements f are all $E(0)/\alpha$, (see (**9**)); or, since here $E(0) = 1$, $\dfrac{1}{\alpha}$. The $n-1$ constants $(B_1, \ldots B_{n-1})$ must therefore satisfy the n linear equations

$$\frac{B_1}{b_r - \beta_1} + \frac{B_2}{b_r - \beta_2} + \ldots + \frac{B_{n-1}}{b_r - \beta_{n-1}}$$

$$= \frac{1}{\alpha} - \frac{B}{b_r + i\,\omega}; r = 1, 2, \ldots n \qquad (\mathbf{23})$$

That these equations are not independent follows at once on multiplication by $(\alpha_1, \ldots \alpha_n)$ and addition when both sides vanish. To find the values of the B's, consider the analysis of the quotient $(x + b_1) \ldots (x + b_n)/(x - i\,\omega)\,\varphi(x)$ into its simple fractions. Writing it in the form $1 + \dfrac{g(x)}{(x - i\,\omega)\,\varphi(x)}$ where $g(x)$ is of lower degree than n, we find

$$\frac{(x + b_1) \ldots (x + b_n)}{(x - i\,\omega)\,\varphi(x)} = 1 + \frac{(b_1 + i\,\omega) \ldots (b_n + i\,\omega)}{\varphi(i\,\omega)\,(x - i\,\omega)}$$

$$- \sum_r \frac{(b_1 - \beta_r) \ldots (b_n - \beta_r)}{(\beta_r + i\,\omega)\,\varphi'(-\beta_r)\,.\,(x + \beta_r)}$$

Setting $x = (-b_1, -b_2, \ldots -b_n)$ in turn in this identity, we obtain the n relations

$$\sum_r - \frac{(b_1 - \beta_r) \ldots (b_n - \beta_r)}{(\beta_r + i\,\omega)\,\varphi'(-\beta_r)\,(b_s - \beta_r)}$$

$$= 1 - \frac{\alpha\,B}{b_s + i\,\omega}; s = 1 \ldots n;$$

and on comparing these with (**23**) we see that the $n-1$ quantities $(B_1, \ldots B_{n-1})$ are given by the formulas

$$B_r = -\frac{1}{\alpha} \cdot \frac{(b_1 - \beta_r) \ldots (b_n - \beta_r)}{(\beta_r + i\,\omega)\,\varphi'(-\beta_r)} \qquad (\mathbf{24})$$

From this it follows that

$$B_r = A_r \frac{\beta_r}{\beta_r + i\,\omega} \qquad (\mathbf{25})$$

where the A's are the constants of the unit e. m. f. case whose values have been given in (**17**).

If we introduce the time constants T_r which are the reciprocals of the β_r, our equation (**25**) takes the form

$$B_r = A_r/(1 + i\,\omega\,T_r) \qquad (\mathbf{25}^{bis})$$

The two-layer dielectric in an alternating field.

Here the equation for the constant B is

$$B = \frac{(i\,\omega + b_1)\,(i\,\omega + b_2)}{(\alpha_1 b_2 + \alpha_2 b_1) + (\alpha_1 + \alpha_2)\,i\,\omega}$$

$$= \frac{(i\,\omega + b_1)\,(i\,\omega + b_2)}{(\alpha_1 b_2 + \alpha_2 b_1)\,(1 + i\,\omega\,T)} \qquad (\mathbf{26})$$

This is but a particular case of the general formula (see (**21**))

$$B = \frac{(i\,\omega + b_1) \ldots (i\,\omega + b_n)}{\alpha\,\phi(i\,\omega)}$$

$$= \frac{(i\,\omega + b_1) \ldots (i\,\omega + b_n)}{\alpha\,(i\,\omega + \beta_1) \ldots (i\,\omega + \beta_{n-1})}$$

$$= \frac{(i\,\omega + b_1) \ldots (i\,\omega + b_n)}{b_1 \ldots b_n \left(\sum_r \frac{\alpha_r}{b_r}\right)(1 + i\,\omega\,T_1)(1 + i\,\omega\,T_2) \ldots (1 + i\,\omega\,T_{n-1})} \qquad (\mathbf{27})$$

Since

$$\alpha\,\beta_1 \ldots \beta_{n-1} = \alpha\,\varphi(0) = b_1 \ldots b_n \left(\sum_r \frac{\alpha_r}{b_r}\right)$$

In Wagner's notation (**26**) takes the form

$$\frac{\left(\lambda_1 + i\frac{\omega\,\epsilon_1}{\gamma}\right)\left(\lambda_2 + i\frac{\omega\,\epsilon_2}{\gamma}\right)}{(a_1 \lambda_2 + a_2 \lambda_1)\,(1 + i\,\omega\,T)}$$

or

$$\frac{\left(\lambda_1 + i\frac{\omega\,\epsilon_1}{\gamma}\right)\left(\lambda_2 + i\frac{\omega\,\epsilon_2}{\gamma}\right)}{a_1 \lambda_2 + a_2 \lambda_1 + i\,\omega\,\frac{a_1 \epsilon_2 + a_2 \epsilon_1}{\gamma}}.$$

Similarly, the general expression (**27**) for n layers becomes

$$B = \frac{\left(\lambda_1 + i\,\omega\frac{\epsilon_1}{\gamma}\right) \ldots \left(\lambda_n + i\,\omega\frac{\epsilon_n}{\gamma}\right)}{\lambda_1 \ldots \lambda_n \left(\sum_r \frac{a_r}{\lambda_r}\right)(1 + i\,\omega\,T_1) \ldots (1 + i\,\omega\,T_{n-1})} \qquad (\mathbf{27}^{bis})$$

In the two-layer cases the constant B_1 in the complete expression

$$u = B\,e^{i\omega t} + B_1\,e^{-\beta_1 t} = B\,e^{i\omega t} + B_1\,e^{-t/T}$$

has the value

$$B_1 = \frac{A_1}{1 + i\,\omega\,T} = \frac{(\lambda_2\,\epsilon_1 - \lambda_1\,\epsilon_2)^2}{(a_1\,\epsilon_2 + a_2\,\epsilon_1)^2\left(\frac{\lambda_1}{a_1} + \frac{\lambda_2}{a_2}\right)(1 + i\,\omega\,T)}$$

from (**19**) (**28**)

When $\omega = 0$ the expression (**27**^{bis}) reduces to the con-

duction current $\dfrac{1}{\sum_r \dfrac{a_r}{\lambda_r}}$ under a constant unit e. m. f.

If the dielectric were uniform, the electric intensity would be $\dfrac{1}{\sum_r a_r}$ and so we write $\lambda = \dfrac{\sum_r a_r}{\sum_r \dfrac{a_r}{\lambda_r}}$ and call it the effective conductivity. For very high frequency we see from (**21**) that B tends to $\dfrac{i\,\omega}{\alpha}$ *i. e.*, $\dfrac{i\,\omega}{\gamma \sum_r \dfrac{a_r}{\epsilon_r}}$.

Writing $\epsilon = \dfrac{\sum_r a_r}{\sum_r \dfrac{a_r}{\epsilon_r}}$ for the capacity constant of the dielectric for very high frequencies, we may consider the difference

$$(\Sigma\, a_r)\, B - \left(\lambda + i\,\omega\,\frac{\epsilon}{\gamma}\right) = \bar{\lambda} + i\,\omega\,\frac{\bar{\epsilon}}{\gamma}, \text{ say, as}$$

due to the lack of homogeneity of the dielectric. Writing B in the form

$$B = \frac{(i\,\omega + b_1)\;.\;.\;.\;(i\,\omega + b_n)}{\alpha\,\phi\,(i\,\omega)}$$

the difference in question is the product of $\sum_r a_r$ and

$$\frac{(i\,\omega + b_1)\;.\;.\;.\;(i\,\omega + b_n)}{\alpha\,\phi\,(i\,\omega)} - \frac{b_1\;.\;.\;.\;b_n}{\alpha\,\phi\,(0)} - \frac{i\,\omega}{\alpha}$$

On reducing to a common denominator the numerator lacks the term in ω_n and also the constant term. Thus in the case $n = 2$ where $\phi\,(i\,\omega) = i\,\omega + \beta_1 = i\,\omega + \dfrac{1}{T}$

the numerator is $i\,\omega \left[\dfrac{b_1 + b_2}{T} - \dfrac{1}{T^2} - b_1\,b_2\right]$ or

$\dfrac{i\,\omega\,\alpha_1\,\alpha_2\,(b_2 - b_1)^2}{(\alpha_1 + \alpha_2)^2}$ since $\dfrac{1}{T} = \dfrac{\alpha_1\,b_2 + \alpha_2\,b_1}{\alpha_1 + \alpha_2}$.

Hence $\bar{\lambda} + i\,\omega\,\dfrac{\bar{\epsilon}}{\gamma}$

$$= \frac{(a_1 + a_2)\,i\,\omega\,\alpha_1\,\alpha_2\,(b_2 - b_1)^2}{(\alpha_1 + \alpha_2)^2\,(\alpha_1\,b_2 + \alpha_2\,b_1)\left(i\,\omega + \dfrac{1}{T}\right)}$$

$$= \frac{(a_1 + a_2)\,i\,\omega\,\alpha_1\,\alpha_2\,(b_2 - b_1)^2}{(\alpha_1 + \alpha_2)\,(\alpha_1\,b_2 + \alpha_2\,b_1)^2\,(1 + i\,\omega\,T)}$$

In Wagner's notation this is

$$\frac{i\,\omega\,(a_1 + a_2)\,(\lambda_2\,\epsilon_1 - \lambda_1\,\epsilon_2)^2}{\gamma\,(1 + i\,\omega\,T)\,(a_1\,\lambda_2 + a_2\,\lambda_1)^2\left(\dfrac{\epsilon_1}{a_1} + \dfrac{\epsilon_2}{a_2}\right)}$$

Writing this in the form $\dfrac{i\,\omega\,\epsilon\,.\,k}{\gamma\,(1 + i\,\omega\,T)}$ the "absorption constant" k has the value

$$k = \frac{a_1\,a_2\,(\lambda_2\,\epsilon_1 - \lambda_1\,\epsilon_2)^2}{\epsilon_1\,\epsilon_2\,(a_1\,\lambda_2 + a_2\,\lambda_1)^2} \tag{29}$$

Writing $a_2 = m\,a_1$ this becomes $\dfrac{m\,(\lambda_2\,\epsilon_1 - \lambda_1\,\epsilon_2)^2}{\epsilon_1\,\epsilon_2\,(\lambda_2 + m\,\lambda_1)^2}$; regarded as a function of m it has a maximum value when $m = \dfrac{\lambda_2}{\lambda_1}$, the corresponding value of k being $\dfrac{(\lambda_2\,\epsilon_1 - \lambda_1\,\epsilon_2)^2}{4\,\epsilon_1\,\epsilon_2\,\lambda_1\,\lambda_2}$. If the dielectric consists of paper with impurities in the form of moisture, we may set $\lambda_1 = 10^{-11}$, $\epsilon_1 = 2$ (paper) and $\lambda_2 = 10^{-4}$, $\epsilon_2 = 80$ and k becomes $0.025\ m$.

We may indicate, in conclusion, some of the calculations for the three-layer case although some of the formulas become quite complicated. Here there are two exponential terms and $-\beta_1$, $-\beta_2$ are the zeros of the quadratic polynomial

$$\alpha\,\phi\,(x) = (\alpha_1 + \alpha_2 + \alpha_3)\,x^2 + \{\,\alpha_1\,(b_2 + b_3) + \alpha_2\,(b_3 + b_1) + \alpha_3\,(b_1 + b_2)\,\}\,x + \alpha_1\,b_2\,b_3 + \alpha_2\,b_3\,b_1 + \alpha_3\,b_1\,b_2$$

We have $\phi\,(i\,\omega) = (i\,\omega + \beta_1)\,(i\,\omega + \beta_2) = (1 + i\,\omega\,T_1)\,(1 + i\,\omega\,T_2)/T_1\,T_2$; the numerator of the expression $\bar{\lambda} + i\,\omega\,\dfrac{\bar{\epsilon}}{\gamma}$ has two terms, one involving ω and the other ω^2. On using the relations

$$\frac{1}{T_1\,T_2} = \frac{\alpha_1\,b_2\,b_3 + \alpha_2\,b_3\,b_1 + \alpha_3\,b_1\,b_2}{\alpha_1 + \alpha_2 + \alpha_3};$$

$$\frac{1}{T_1} + \frac{1}{T_2} = \frac{\alpha_1(b_2+b_3) + \alpha_2(b_3+b_1) + \alpha_3(b_1+b_2)}{\alpha_1 + \alpha_2 + \alpha_3}$$

we find

$$\bar{\lambda} + i\,\omega\,\frac{\bar{\epsilon}}{\lambda} = \frac{i\,\omega\,(a_1 + a_2 + a_3)\,[L + M\,i\,\omega]}{\dfrac{(\alpha_1+\alpha_2+\alpha_3)(\alpha_1\,b_2\,b_3+\alpha_2\,b_3\,b_1+\alpha_3\,b_1\,b_2)^2}{(1 + i\,\omega\,T_1)\,(1 + i\,\omega\,T_2)}}$$

where

$$L = \alpha_1 \alpha_2 b_3^2 (b_1 - b_2)^2 + \alpha_2 \alpha_3 b_1^2 (b_2 - b_3)^2 + \alpha_3 \alpha_1 b_2^2 (b_3 - b_1)^2$$

$$M = \alpha_1 \alpha_2 b_3 (b_1 - b_2)^2 + \alpha_2 \alpha_3 b_1 (b_2 - b_3)^2 + \alpha_3 \alpha_1 b_2 (b_3 - b_1)^2.$$

We hope in a second paper to give a rigorous proof of the Boltzmann-Hopkinson Principle of Superposition, from which all the formulas given above for the alternating case can be deduced, and to apply it to the case $E = t$ where an e. m. f. with constant time gradient is applied.

Note on the analysis of a quotient of two polynomials into simple fractions.

The quotient $G(x)/F(x)$ where $G(x)$ is a polynomial of degree less than n and $F(x) = (x - x_1) \ldots (x - x_n)$ may be written in the form

$$\frac{G(x)}{F(x)} = \frac{A_1}{x - x_1} + \ldots + \frac{A_n}{x - x_n}$$

where $(A_1, \ldots A_n)$ are constants to be determined. To find them we multiply up by $x - x_1$, say, and then let $x = x_1$ giving

$$\frac{G(x_1)}{(x_1 - x_2) \ldots (x_1 - x_n)} = A_1.$$

Now $F(x) = (x - x_1) H(x)$, say, where $H(x) = (x - x_2) \ldots (x - x_n)$ and so the ordinary rule for the derivative of a product gives $F'(x) = H'(x) \cdot (x - x_1) + H(x)$

Whence

$$F'(x_1) = H(x_1) = (x_1 - x_2) \ldots (x_1 - x_n)$$

Hence

$$A_1 = \frac{G(x_1)}{F'(x_1)} \text{ and, in general, } A_r = \frac{G(x_r)}{F'(x_r)}.$$

We have supposed here, as is the case in the text, that no two of the numbers $(x_1, x_2, \ldots x_n)$ are equal.

Abridgment of

The Induction Lamp, a New Source of Visible and Ultra-Violet Radiation

BY TED E. FOULKE*

Non-Member

Synopsis.—*This paper deals with the induction lamp, or more generally speaking, the electrodeless electrical discharge. This lamp is a rich source of visible and ultra-violet radiation. The lamp has no electrodes, no conducting filaments and no conducting arc, as ordinarily understood. It operates on the principle of the electrodeless discharge which is produced in a partly exhausted vessel within a rapidly changing electromagnetic field. The discharge consists of visible and invisible radiations. The paper contains a historical introduction, an explanation of the theory of the electrodeless discharge and a description of the results of experiments.*

* * * * *

Historical Introduction

THE first account of the electrodeless discharge was given by Sir J. J. Thomson[1] and describes the glow that is set up in a partly exhausted vessel by the discharge of a condenser through a coplanar coil surrounding it. In his experiments a Wimshurst machine was used to charge the condensers and the discharge took place through the coil and between the spark gap terminals which consisted of two polished balls in air. This arrangement is clearly shown in Fig. 1, in which it will be observed that there are no electrical connections with the gas within the vessel. The electrodeless discharge, according to Thomson, was explained by the voltage induced in the space surrounded by the coil.

During recent years many carefully interpreted experiments have been carried out to explain the influence of electron velocity on the spectra and ionization of atoms and molecules. Other experiments deal with a mixture of atoms or molecules part of which have become active either by the absorption of radiation of the proper frequency or by the impact with rapidly moving electrons. The correlation of these isolated facts with the experimental data on the electrodeless discharge leads to an understanding of the mechanism of this type of discharge.

Theory of the Electrodeless Discharge

The phenomenon in this case is to a certain extent similar to that which occurs in the secondary of a high-frequency transformer in which the secondary consists of a closed ring of variable conductance. The essential difference lies in the fact that the induced e. m. f. must exceed a certain critical voltage, known as the ionization potential, before the gas becomes conducting. The conducting or ionized state is due to the impact of electrons with the atoms or molecules of the gas.

To understand the mechanism of the induction discharge we must consider separately the three-fold

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*Cooper Hewitt Electric Company.

1. J. J. Thomson, *Phil. Mag.*, Vol. 32, 1891.

purpose of the gas. The first is its functioning as a source of the initial electrons; second, its property of becoming ionized when placed in a rapidly changing electromagnetic field; and third, its ability to emit radiation. The first function arises in the capability of all substances, to a certain extent, to absorb the highly penetrating radiation that permeates all space, the atmosphere of our earth, and, at least for a certain distance, all solid bodies. The absorption of this radiation by atoms or molecules, particularly in the gaseous state, causes the ejection of one or more electrons from them.

The atom or molecule in this state possesses a residual positive charge and is capable of moving in an electrostatic field; it is then called an ion. It has been found from experiment that about one to ten atoms or molecules are split up in this fashion per sec. per cu. cm. at atmospheric pressure and temperature. The number of electrons generated in this manner is insignificant in constituting a flow of current when we stop to consider that a flow of one ampere corresponds to 10^{18} electrons per sec.

The second characteristic of the gas is its ability to become ionized by the impact of electrons with the

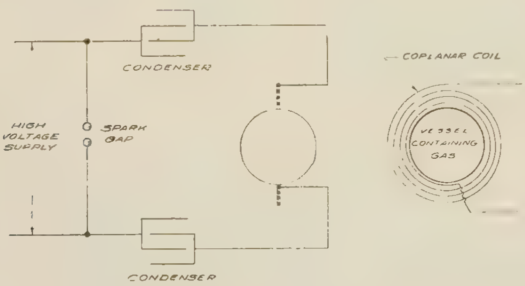


FIG. I—THE ELECTRICAL ARRANGEMENT, AND EDGEWISE VIEW OF COPLANAR COIL SURROUNDING VESSEL IN WHICH ELECTRODELESS DISCHARGE TAKES PLACE

atoms or molecules of the gas. The equivalent difference of potential through which an electron must fall to gain sufficient kinetic energy to ionize an atom or molecule, lies between 3.9 volts and 24.5 volts, as shown in the following table:

Atom	Minimum Critical Voltage
Caesium	3.9
Sodium	5.1
Mercury	10.4
Argon	15.5
Nitrogen	16.3
Helium	24.5

Thus, starting with the feeble ionization produced by the penetrating radiation, it is possible by means of the induced electromotive force to increase greatly the state of ionization and consequent conductivity of the gas. This process is termed ionization by collision.

The third function of the gas is to emit radiation. To be specific, this radiation is chiefly discontinuous in so far as it differs from the continuous band of radiation from incandescent radiators. The characteristic radiation from the atom is of the monochromatic type, that is, it consists of a series of discrete wave lengths, whereas the radiation from molecules though monochromatic in detail gives rise to bands of radiation that cover large wave-length intervals.

According to modern theory, atoms and molecules possess discrete stationary energy states. The normal energy state is the one in which we find them under ordinary conditions and by the expenditure of energy higher states may be obtained, for instance, by the impact of a rapidly moving electron with an atom or molecule. The transition from a low energy state to a high energy state takes place only when the available energy is equal to, or greater than, the difference between the two energy levels. When the atom returns to the normal state the energy is given up in the form of radiation of a definite frequency.

A formal explanation of the stationary energy state can best be obtained from Bohr's theory. In the simplest atom, that of hydrogen, Bohr postulates a single electron rotating around a central positive nucleus which, contrary to the electromagnetic theory, does not radiate according to the frequency of rotation. The energy in a definite orbit is equal to the sum of the kinetic and potential energies and is calculated accordingly from simple mechanics. Bohr postulates that only orbits of a definite radius are permissible and so determined that

$$2\pi \times \text{angular momentum} = n\,h$$

He then arrives at the energy in any state n

$$W_n = \frac{2\pi^2 m e^4}{h^2}\,\frac{1}{n^2}$$

where

W_n = the energy in the stationary state n
n = assumed integral values 1, 2, 3, etc.
e = the charge on the electron
m = the mass of the electron
h = Plancks constant

If we then let W_a be the energy in the normal state and W_e be the energy in a higher state corresponding to an orbit of larger radius, then the energy required to bring about this transition is

$$\Delta E = (W_a - W_e)$$

After the atom absorbs the energy ΔE and charges to the high energy level, it is in an unstable condition from which it returns in a short interval of time—with the exceptlon of a few cases, in about 10^{-8} seconds. The return to the lower energy level is accomplished by the liberation of energy in the form of monochromatic radiation. The relation between the energy and the frequency of radiation is given by the following relation:

$$\Delta E = (W_e - W_a) = h\,\nu$$

where

ν = the frequency of radiation

Atoms and molecules possess a large number of energy states and once put into the higher energy levels may return to the normal state, that in which they exist under ordinary conditions directly by emitting radiation of the frequency

$$\nu = \frac{\Delta E}{h}$$

or indirectly through a series of intermediate levels.

In order to gain a better picture of the energy levels in an atom the levels and wave lengths due to a few transitions between them are plotted in Fig. 2 for the mercury atom.

The normal state is indicated by $1\,S$ and the other levels represent excited states. The wave length in angstrom units and the relative intensity are marked on the lines showing transitions that occur. Not all possible transitions occur as will be observed on this

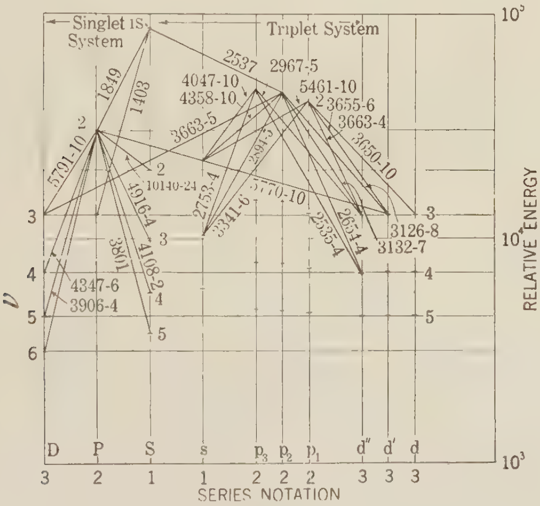


Fig. 2—A Few Energy Levels In Neutral Mercury

Transitions from high orbit numbers "or high energy states" to low orbit numbers causes emission of monochromatic radiation. It will be observed that the high energy levels actually correspond to low relative energy.

diagram. Each atom has its own series of levels and the transitions between them produce spectral lines that are characteristic of the individual atom.

The life of an excited atom is of the order 10^{-8} sec., but in a few cases a return to the normal state does not occur until the atom absorbs additional energy or is disturbed by a collision with a neutral atom. In the latter case the return to the normal state may occur by activating the neutral atom, or both impacting bodies can take up the energy in the form of translational kinetic energy. In either case the originally excited atom returns to the normal state without the emission of radiation. This type of encounter is called a collision of the second kind to distinguish it from the type of impact in which an electron or atom of high kinetic energy transfers this energy to another atom which then becomes excited.

We will now try to show the various factors that govern the character of the electrodeless discharge in a gas or vapor. Let us first of all consider a vessel exhausted under conditions such that a perfect vacuum is attained. When the vessel is placed in a rapidly changing electromagnetic field an induced e. m. f. will be set up, but as the vessel is free of gas, free electrons will not exist and current cannot flow. The addition of a small quantity of gas causes the spontaneous formation of ions and electrons by the penetrating radiation. Under the action of the induced voltage the positive ions start to move in one direction and the electrons in the other, constituting a flow of current. This current, as was previously pointed out, is insignificant if not further amplified. The current can be increased, however, by ionization by collision. It has been found by experiment that the electrons are the most effective in the ionizing process. The positive ions formed, while not important in the ionization of the gas, do play an important role in their space charge effects. Two conditions are necessary before an electron can ionize. First, the electron must gain a velocity and corresponding kinetic energy great enough to cause ionization of the gas, and second, the electron once having gained sufficient energy must then encounter an atom before it loses its energy, either by going against a reverse potential or by colliding with the walls of the vessel and dissipating its available energy. The probability that an electron will collide with an atom of the gas will depend on the density or pressure of the gas and on the free path of the electron in the gas. The mean free paths of electrons in several gases have been calculated from the kinetic theory values at one bar.

Gas	Mean free path of electron at 1 bar[2]
	C
Helium	165. cm.
Hydrogen	108. "
Argon	60. "
Nitrogen	56. "
Mercury	18. "

In discharge conditions available in the laboratory we must necessarily use vessels of practical size. These may be several centimeters and seldom greater than 30 cm. in diameter. An electron traveling in the largest circle of a 30-cm. bulb would make but one collision per revolution in argon at one bar and in mercury about five collisions at the same pressure. In a 2-cm. bulb the electron would make, on the average, one collision per ten revolutions in argon at one bar and one collision per three revolutions in mercury at one bar. It has been observed as an experimental fact that the gas does not become highly conducting until the electron makes many encounters per revolution.

The electrons in colliding with atoms of the gas do not lose an appreciable energy to the atoms unless their

2. 1 bar = 0.00075 mm.

available energy is greater than that required to cause a transition between two energy levels. There is, however, a small loss due solely to the elastic impact between the two bodies. The electron on colliding with an atom loses on the average a fraction of its energy equal to

$$\theta = \frac{1}{2} \frac{m}{M} E$$

where

θ = the fraction of energy transferred to the atom
E = the kinetic energy of the electron
m = the mass of the electron
M = the mass of the atom

The fraction θ for electron impacts with argon and mercury atoms is of the order 10^{-5}, an insignificant amount per collision. At low pressures this loss does not play any part in the ionization and conduction, but at moderate pressures, of the order of a centimeter pressure of mercury, the loss in energy per centimeter of path traveled is appreciable. At high pressures the loss entailed simply by elastic collisions is so great that an electron cannot gain sufficient energy to excite or ionize the gas, and the latter is in a state of low conductivity.

We see, therefore, that an optimum condition exists wherein the electron makes enough ionizing collisions to bring about a state of high conductivity and excitation, and not enough to cause serious losses due solely to elastic impacts.

Let us now consider the effect of pressure on the degree of excitation and the spectral transitions that occur. When the pressure is low and the mean free path is long, the electrons as a whole will have high velocities and thus will be able to cause the atom to become highly excited. This may mean, according to the Bohr theory, that the valence electron goes into an outer orbit, or that the electron gets beyond the influence of the positive nucleus and this is detached from the parent atom. In the case of mercury the latter will occur when the atom absorbs 10.4 volts energy from the electron. Still higher excitation may occur where the second valence electron is ejected into an outer orbit or so-called higher energy level. As the pressure increases the average electron velocity decreases because of the more frequent loss of energy by excitation and by elastic impacts. At high pressure the energy is controlled mainly by the elastic impacts and the electron reaches a final velocity depending on the voltage gradient and free path.

In strong discharges transition to the higher levels and complete ionization may occur, due to the fact that enormous numbers of excited atoms present in the low energy levels are bombarded by electrons having energy insufficient to ionize directly. The excited atoms are produced both by electron impact and by collision of the second order.

In a mixture of gases the excitation and ionization is usually due to the constituent of greater concentration, or more particularly, shorter mean free path or shorter ionization path, though this by no means indicates that the radiation is characteristic of this constituent. If the constituent of low concentration has lower energy levels, the excited atoms of the first type which are strongly stimulated by the discharge current will activate the atoms of lower energy levels by collision of the second order. In this manner relatively small quantities of gas of lower energy levels will determine the radiation obtained. In case the atoms of lower concentration have energy levels in excess of those primarily stimulated by the electron current, the spectra of the stimulated atoms only show up in the discharge. These atoms of higher energy level, however, do influence the primary stimulated atoms. This arises in their collision with excited atoms. Though their excitation levels are higher than those of the excited atoms, an impact of the second order may occur wherein the excited atom becomes unexcited and both the previous excited atom and the high energy level atom become atoms of high kinetic energy. These high speed atoms may then collide with other atoms or molecules of the gas, subdividing the kinetic energy until they reach temperature equilibrium.

Experimental Methods

Electrical Arrangement. The arrangement of the electrical circuit has been studied with a variety of connections, but all come under two general classes. One class consists of a high voltage transformer 3000 to 15,000 secondary voltage, one or more condensers, 0.001 m. f. to 0.050 m. f., a spark gap and the helical exciting coil; the other class involves the use of a high voltage, either a-c. or d-c., one or more pliotrons, condensers and helical coil to excite the lamp. Two typical schemes for a-c. lamps are shown in Plate II.

An example showing the apparatus of the spark converter type necessary to operate efficiently a 3.8-cm. radius mercury argon induction lamp is given in the following table:

Exciting Helix	—7 turns copper, 4-cm. radius, 1.0-cm. separation
Condenser	—0.005 μ f.
Spark Gap	—4 G. E. navy type units S. E.–1001 or equivalent
Choke Coil	—30 millihenrys
Transformer	—5500-volt secondary, high-reactance type

Calorimeter. The principle of the calorimeter shown in Fig. 3 is quite simple. It consists of an air-tight thermally insulated box through which air is blown at a constant pressure difference between the intake and exit ports. The walls are blackened with the exception of a small glass window used in making photometric measurements. There are also suitably placed baffles which force the air to circulate around the lamp and box before leaving it. When power is dissipated in the box (for instance, by an induction lamp or the filament of an incandescent lamp), the walls and the gas rise in temperature. It has been observed as an experimental

fact that the temperature of the issuing gas measured with an ordinary thermometer (under fixed conditions) will rise with time according to the following empirical relation:

$$t = C\,\epsilon^{\frac{T}{KW}}$$

where

t = Time
T = Temperature
W = Watts input
C, K = Constants

The form in which we actually use this relation is given below:

$$W = \frac{\log_{10}\epsilon}{K}\;\frac{\Delta T}{\Delta \log_{10} t} = K_1 S$$

While no attempt has been made to secure an accuracy greater than a few per cent, it can be said that during a period of over one year, we obtained consistent results under widely different operating conditions.

Photometry. The illumination from the induction lamp was measured during the calorimetry period. (See Fig. 3). A glass window placed in one end of the calorimeter allowed the light from the lamp to fall on a

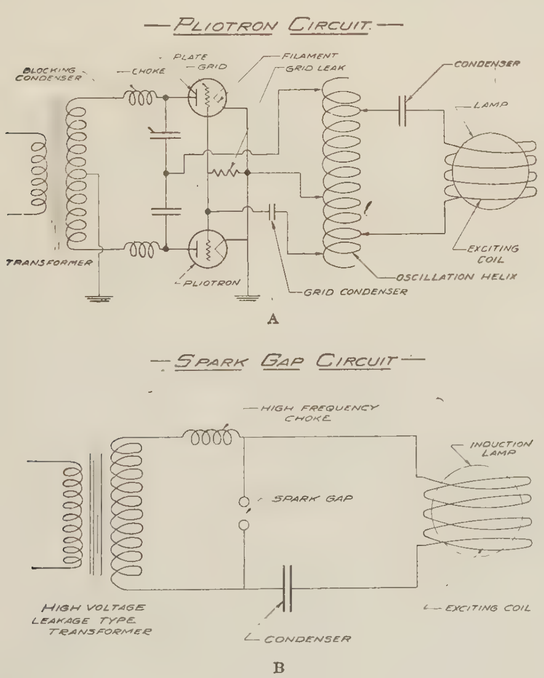


Plate II

photometer head or test plate. Either a MacBeth illuminometer or a Sharp-Miller photometer was used to determine the horizontal candle power from the lamp. To obtain consistent results over a long period of time three carefully seasoned lamps were calibrated against lamps rated at the Bureau of Standards. The working standards were used only a few minutes a day.

The absorbing screens supplied with the MacBeth illuminometer were used for medium candle power readings and rotating sectors for high intensity measurements. A considerable part of our work has been done on colored lights and it seemed best to learn to match light by intensity, irrespective of the color difference. This end, we believe, has been accomplished, for in several cases we were able to check ourselves by placing an absorbing screen in the eye-piece that reduced the color difference without an appreciable change in the intensity match. The errors that did arise, we believe, are small in comparison to the relative changes in intensity that were involved.

Energy Measurements. The distribution of energy in

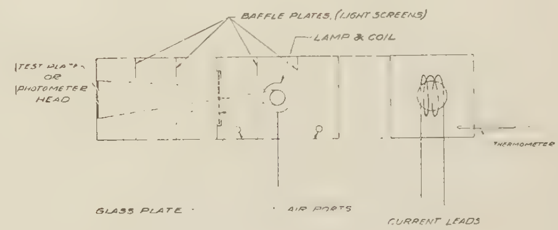


Fig. 3—The Combination Calorimeter and Photometer

the spectrum of the induction discharge has been determined by two methods. The first method separates the far infra red radiation from the easily obtained spectral region which lies in the range 20,000 Å to 1900. Å. The method consists in the use of a shielded thermopile calibrated to read energy incident on it and suitable filters to separate out certain spectral regions. In the second method a quartz spectrograph is used and a thermopile is so mounted on a carriage that it can be placed at the focus of each spectral line. The instrument used in this work had a working range of 60 mm. between 5700 Å and 2100 Å and the slit width limiting the beam falling on the thermopile was approximately 0.3 mm.

Preparation of the Lamp. The lamp is prepared usually in the form of a spherical bulb. This may consist of soft or hard glass, pyrex, or transparent quartz, depending on the use to which it is to be put. The bulb is exhausted to a pressure of one micron and preferably less. A furnace is then lowered over the bulb and raised to as high a temperature as possible. Soft glass usually can be heated to 400 deg. cent., 702-*P* and pyrex to about 550 deg. cent and quartz nearly to 1000 deg. cent. After a short bake-out of ten minutes or longer, with liquid air on the system, the oven is raised and the lamp is partly cooled. The spectral substance, solid liquid or gas, is now put in the bulb. In the case of the mercury lamp liquid mercury is either distilled or run into the bulb and then boiled to free it of all water vapor and occluded gases. While the mercury is warm an induction discharge of an extreme intensity is set up in the lamp for several minutes with the vacuum pumps running. This bombarding of the bulb walls is quite the most im-

portant treatment as it liberates gas that no amount of heating seems to free. It is also very important that the residual gas pressure should be below a micron (0.001 mm.) as the nitrogen reacts immediately causing a golden brown film to form on the bulb.

It is advisable to torch the contraction and then fill the bulb with the auxiliary starting gas which is ordinarily one of the rare gases. This gas should be particularly free of all ordinary gases. After filling to the proper pressure, the lamp is sealed off from the exhausting system and "seasoned" as an induction lamp.

Discussion of Results

The Effect of Vapor Pressure. An induction discharge cannot occur in pure mercury vapor at ordinary room temperature because the pressure of the vapor is too low to sustain a discharge. This is due to the long free path of the electrons in the gas. By raising the temperature of the liquid mercury, the vapor pressure rises until the free path is sufficiently short and discharge occurs. The intensity of the discharge is at first weak

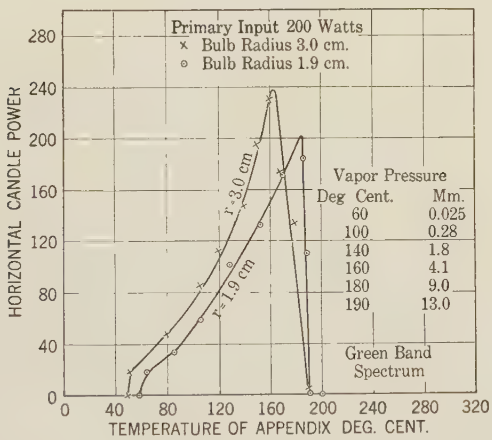


Fig. 4—Showing the Effect of Temperature of Liquid Mercury on the Luminous Output

but increases with further increase in pressure until a final maximum is reached. A further increase in temperature practically stops the strong discharge and a weak emerald green glow takes its place. Above the maximum critical pressure the electrons make so many collisions with the atoms and molecules of the gas that the loss entailed merely in perfect elastic encounter reduces their velocity and corresponding energy below that which is required to put the gas in a strongly ionized condition. A typical curve showing the effect of temperature on the luminosity is given in Fig. 4.

While the variation of maximum critical pressures with electromotive force has as yet not been studied in detail, theoretical considerations suggest that the terminal velocities of the electrons are proportional to X/p, where X and p are the electric intensity and pressure, respectively. Thus if p exceeds X/U, where U is the ionizing voltage, the discharge stops. The conclusion can be drawn, therefore, if this assumption is correct, that the maximum critical pressure is proportional to X.

Now it is known that once a strong discharge is started, the pressure can be carried above the value corresponding to the starting condition. This suggests that the electron energy U required to sustain the ionized condition is lower where a strong degree of excitation exists. We therefore have evidence for believing that under steady operation at high pressures the ionization of the gas occurs not essentially by single impacts but by successive additions of energy to the atoms.

The Effect of the Bulb Size. Early experiments at low power input indicated that the luminous output of pure mercury induction discharge was proportional to the radius of the discharge bulb and the square of the wattage. Data secured on bulbs of different radii could be approximately expressed by the equation

$$B = c\, r\, w^2$$

where

B = the horizontal candle power

r = the radius of the discharge vessel in cms.

w = the primary input watts

c = a constant = 0.77×10^{-3}

The value of c calculated from the data on hand is tabulated below.

Primary watts	Radius of bulb in cm. 2.6	4.6	6.2	7.5	
150	0.87×10^{-3}	1.0×10^{-3}	0.84×10^{-3}	0.86×10^{-3}	
200	0.63	0.71	0.71	0.67	
250	0.83	0.69	0.75	0.69	
300	1.02	0.71	0.65	0.68	
350				0.63	Ave.
	0.84	0.78	0.74	0.71	0.77×10^{-6}

The mercury induction lamps used in securing the above data were heated externally until the discharge occurred. The wattage input was then always kept high enough to maintain sufficient vapor pressure and thus sustain the discharge.

Subsequently the heating was dispensed with. This came about during a study of the effect of the admixture of other gases to mercury vapor. It had been observed that the mercury spectrum appeared in a vacuum system when a low pressure of air was admitted and a spark coil was used to test for leaks. This suggested that a mercury induction lamp could be made self-starting by introducing a low pressure of a permanent gas. When air was used the lamp did operate, but after running a few minutes and then allowing it to cool it failed to start without external heat. This method was bound to fail because, as we found later on, a chemical reaction forming nitride and oxide of mercury cleaned up the air. This short-lived success, however, was followed by a systematic study of the addition of permanent gases to the mercury lamp, and it was found that small quantities of the rare gases could be admitted to the lamp without impairing the mercury spectrum

and at the same time the lamp became permanently self-starting.

After this discovery was made it became a quite simple problem to determine the specific bulb input by calorimetric measurements, and considerable data have been obtained showing the relation between candle power and bulb input for a variety of bulb sizes. A family of curves is shown in Fig. 5.

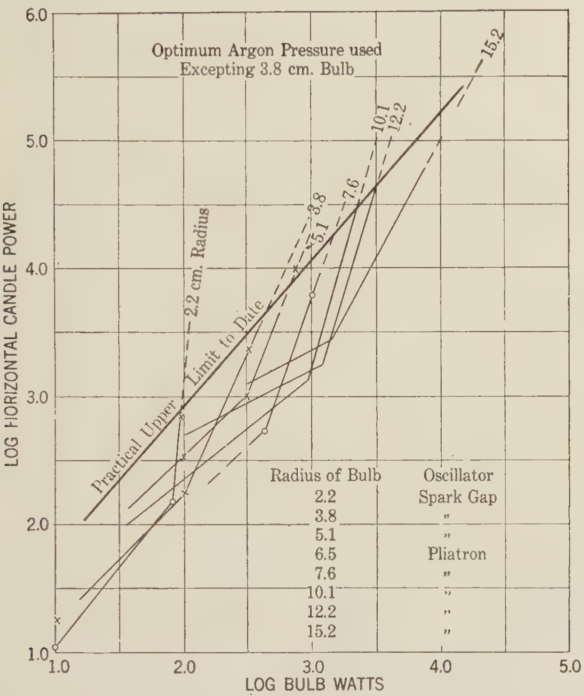


Fig. 5—The Change in Luminous Intensity of a Mercury Argon Lamp With Bulb Input For Various Sized Bulbs

The data presented are averages of a large number of observations and do not mean to imply exact indications or great accuracy. This set of curves represents mercury in combination with argon gas. Particular attention is drawn to the similarity of the curves and to the two definite slopes that make up each curve. There exists a transition region at the intersection of the two curves, though in general the transition is quite sharp. This latter point is shown in a typical plot shown in Fig. 6.

It will be noticed that the transition point shifts to higher wattage with increase in bulb size and suggests that the phenomenon occurring at the transition point is connected with the vapor pressure of the mercury. Assuming that the change occurs at a definite temperature, we would expect to attain the critical temperature when a definite wattage is dissipated per unit area of surface. This assumption leads to the following equation for the critical wattage:

$$W = W_c \, 4 \, \pi \, r^2$$

where

W = the total bulb input at the critical wattage

W_c = the watts per sq. cm.

r = the radius of the bulb

Values of W_c were calculated from existing data.

Radius cm. r	r^2	w	w_c	
2.22	4.49	80	1.41	
3.81	14.5	130	0.71	included
5.10	25.9	316	0.97	included
10.1	102.	1000	0.78	included
12.2	147.	1270	0.69	included
15.2	228.	1860	0.65	included
			Avg......0.76	

It will be observed that on the second part of the curves the illumination tends to follow more nearly the square of the wattage as was found in the case of pure mercury, while at lower input, below the critical point, the slope deviates from unity to values less than this as the diameter of the bulb increases.

The upper limit of luminous output has not been determined as yet. There are limitations that occur. In small lamps, high vapor pressure stops the discharge. This, however, can be overcome by inducing higher voltage. The problem here is one of electrical energy transfer to the bulb. If the vapor pressure is reduced by attaching an appendix to the lamp in which the mercury is maintained at a suitable temperature, the power dissipation becomes so high that the glass is softened and punctures. Resort may then be made to quartz bulbs. In large bulbs the temperature of the glass becomes quite serious because the cost of making large quartz bulbs is at present a serious drawback. From practical consideration a line is drawn across the

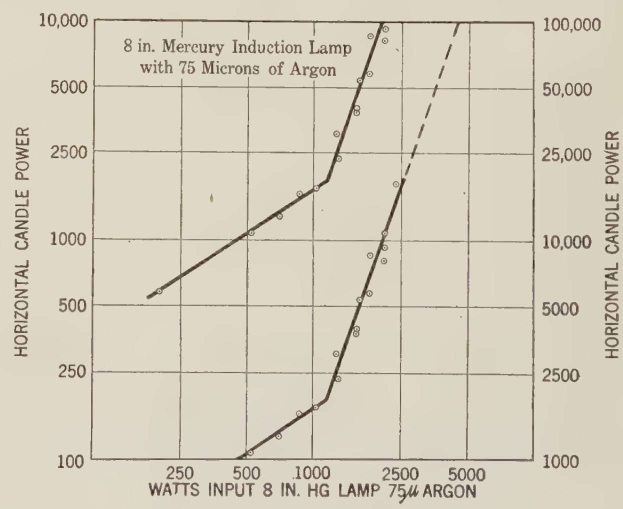


Fig. 6—A Typical "Luminosity-Input" Plot of Data Secured on a 10.1-Cm. Radius, Mercury Argon Induction Lamp

curves showing the upper limits set to date. Our power facilities also limited us in the case of the 12.2-cm. and 15.2-cm. radius bulbs.

Addition of Auxiliary Gas

The auxiliary gas used in the mercury induction lamp seems to play several roles. First in importance is the ability to initiate a discharge, and second is the effect the auxiliary gas atoms have on the mercury atoms

when they interact. Observations at low wattage input indicate that the addition of one of the rare gases to mercury vapor increases the luminous intensity for small pressures of the auxiliary gas. A maximum intensity is obtained at a certain pressure, and with further addition of the rare gas the intensity rapidly decreases. This action is plainly shown in Fig. 7.

A spectral examination under these experimental conditions failed to locate any lines other than those due to the mercury vapor. The spectrum of the rare gas

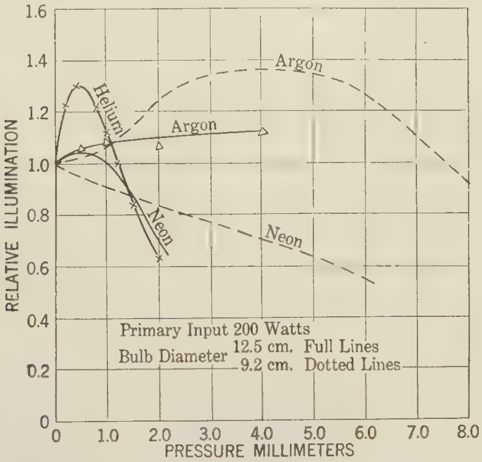


FIG. 7—THE EFFECT ON THE LUMINOUS OUTPUT CAUSED BY ADDING RARE GAS TO A MERCURY INDUCTION LAMP

did show, however, when the lamp was cold, but disappeared as soon as the bulb became warm as in normal operation. Now it is evident that the added gas in small quantities increased the number of excited mercury atoms (that gave rise to the visible radiation) above the number that would normally occur in the mercury vapor alone. The addition of relatively large quantities of auxiliary gas reduced the number of excited mercury atoms below the normal value in pure mercury.

It is reasonable therefore to expect that at low input and low bulb temperature, the pressure of the auxiliary gas will generally be in excess of the pressure of the mercury vapor, and it therefore follows that the initial excitation will take place in the auxiliary gas. Francke and Cario have recently shown that collisions of the second kind very frequently occur, causing a transfer of energy from the excited atom to a neutral atom.

Thus if we follow this line of reasoning we are led to believe that the mercury atoms become excited to a large extent by collisions of the second kind and therefore the visible radiation depends on the number of excited rare gas atoms stimulated in the discharge. Of course some of the mercury atoms will be excited directly but as the concentration of mercury atoms is undoubtedly low at the lower bulb input and temperature it is reasonable to neglect them for the present. In a previous section it was explained that a maximum degree of excitation and ionization was obtained at a certain pressure and above or below this pressure these factors decrease. Thus in the case of the stimulation of a rare gas we can expect a maximum value at a certain pressure and the number of excited rare gas atoms that collide and transfer their energy to mercury atoms will pass through a maximum. Now some of the mercury atoms excited can in turn collide with neutral argon atoms and if a collision of the second kind occurs the excited state disappears in translational kinetic energy of the two atoms. Thus we see that as the pressure of the auxiliary gas increases, the loss of activated mercury atoms increases in proportion to the pressure, which further decreases the luminous intensity.

Following a similar line of reasoning for the case of high bulb input and corresponding temperatures, where the pressure of mercury vapor would be sufficiently high to become excited directly by electron impacts, it would appear that the auxiliary rare gas atoms would be excited very infrequently, as the electron velocity would be reduced by the ionizing and exciting impacts with the mercury. The few collisions of the second kind between excited argon and neutral mercury, therefore, would be unimportant in comparison to the mercury atoms primarily stimulated by the discharge. The presence of the rare gas, however, would cause a serious drain on excited mercury atoms by second order collisions whereby the excited mercury atoms would collide with the neutral auxiliary gas atoms with a loss of the excited state. The energy, of course, would be dissipated in heat, and we conclude

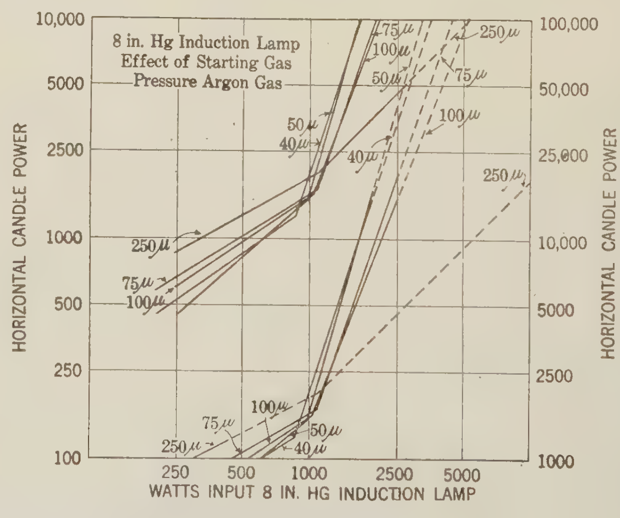


FIG. 8—THE EFFECT OF ADDING ARGON TO A 10.1-CM. RADIUS, MERCURY INDUCTION LAMP

that the addition of a rare gas into a mercury induction lamp which is operated at high bulb input is a decided detriment from the standpoint of luminous output.

This reversal of conditions with small pressures of argon as auxiliary gas is well brought out in Fig. 8 where it will be observed that at low bulb inputs the luminosity is greater (within the range studied) as the pressure is increased, whereas at high wattage, that is, above the critical point, the presence of gas considerably

reduces the luminous intensity. Thus we arrive at the conclusion that the critical point determines the change from excitation of mercury by second order collisions to the direct excitation of the mercury by electron impact.

It is evident from the foregoing that in order to obtain the greatest luminous efficiency and output, the lamp should be operated above the critical point with little more than the minimum amount of gas necessary to initiate a discharge.

It has been found in the case of argon and mercury

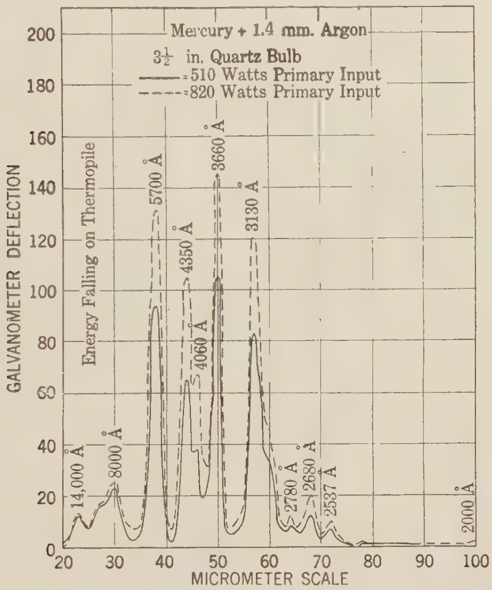


FIG. 9—THE DISTRIBUTION OF ENERGY IN THE RANGE 20,000 Å TO 2000 Å

that this pressure varies inversely as the square of the radius of the bulb and is given by the following empirical relation:

$$p = 5.7\, r^{1/2}$$

p = pressure in mm. of pure argon gas
r = the radius of the discharge vessel in cm.

ENERGY DISTRIBUTION IN THE MERCURY INDUCTION LAMP

Only a few measurements of the radiation efficiency of the mercury induction lamp by the filter method have been made. The results obtained were found to be quite independent of wattage though there does seem to be a difference due to bulb size. The measurements made are listed below.

Bulb radius cm.	Prim. input watts	Energy ratio 18,000Å to 1900Å / total radiation	Energy ratio 3100 Å to 1900 Å / 18,000Å to 1900Å
3.8	460	0.234	
3.8	700	0.23	
3.8	960	0.24	
3.8	240		0.30
3.8			0.31
5.1	400	0.32	0.22

Quartz actually transmits below 1900 Å, but since the quantity transmitted is relatively small, we have neglected the spectral output at shorter wave lengths except in photographic analysis.

Considerable work has been done on the analysis of the spectrum in the range 20,000 Å to 1900 Å by means of the spectrograph and thermopile called the spectroradiometer. A typical energy distribution curve is shown in Fig. 9.

Detailed studies have been made concerning the behavior of some prominent lines in the mercury spectrum. The lines 5700 Å, 5790 Å and 5461 Å in mercury are chiefly responsible for the high luminosity and these three lines are bulked together in the spectraradiogram at approximately 5700 Å. There are three lines of high energy at about 4350 Å but due to the much lower visibility at this wave length these lines only contribute a few per cent to the total luminous output. They do affect, however, the resultant color of the light.

The spectral output of the induction lamp will depend of course on the glass used in the bulb. Ordinary glass will cut off all appreciable energy of wave lengths less than 3400 Å, while pyrex has a transmission limit of about 2970 Å in thin samples. Uviol glass transmits the 2537 Å line quite weakly and quartz will show the 1850 Å line though the transmission is not appreciably below 1900 Å.

The spectra photographed with a glass prism and a quartz prism spectrograph are shown in Plate III.

EFFECT OF FREQUENCY

Experiments have been made at different frequencies varying from 50,000 cycles to about 20,000,000 cycles. The electrical conditions seem to vary considerably over this range. For instance, at 50,000 cycles the current circulating in the helix was about 300 amperes before the discharge occurred, whereas at 20,000,000 cycles the circulating current was only a few tenths of an ampere.

Observations on bulb watts versus luminous output show some variation with frequency, but so far no consistent relation has been found. The data in general included in this paper were secured within the frequency range of 1,000,000 cycles to 3,000,000 cycles.

SPECTRAL SUBSTANCE AND USES

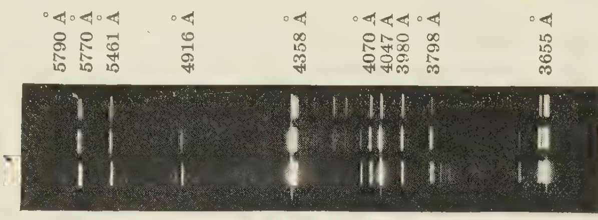
The induction method described in this paper for exciting spectra from atoms and molecules may be used with a variety of substances. For instance, spectra can be obtained without the aid of external heat from over one-third of the elements. Many metallic compounds of low vapor pressure also respond, giving both a line spectrum of the metallic atom and a band spectrum due to the molecule. Space did not allow the discussion of more than one substance, and for this purpose mercury was chosen because of the greater amount of work done on it, but it must be understood that mercury is typical only in so far as it represents the

action in the electrodeless discharge. Each substance, whether element or compound, has its own characteristic spectral distribution. By a suitable choice of substance, therefore, radiation of a particular nature may be obtained; thus some of the elements give only single narrow regions of emission in the infra red, while others emit mostly in the visible or ultra-violet, and still others emit very strongly only in the ultra-violet violet region.

No doubt applications for this type of lamp will be found, for its richness of visible, near ultra-violet and far ultra-violet spectra will adapt it to special uses where the initial cost of the auxiliary equipment will not be of prime importance.

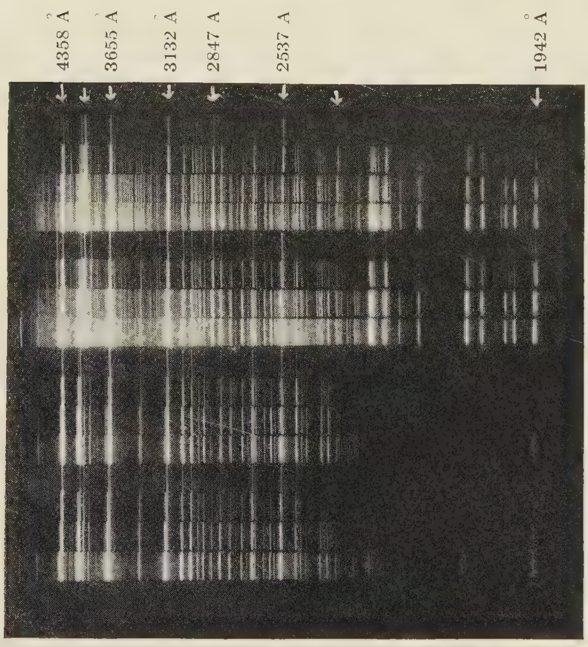
In the visible region efficient illumination can be obtained, while the near ultra-violet region can be used in photography and in fluorescent stage effects. The far ultra-violet region will find its usefulness in therapeutics, sterilization, dye fading, leather processing, promoting photo-chemical action and in the wide open field of research.

A



Exposure Time	Bulb Diameter	Auxiliary Gas	Bulb Input
5 sec.	7.6 cm.	Ar	Low
"	"	"	
"	"	"	High

B



Exposure Time	Bulb Diameter	Auxiliary Gas	Bulb Input
0.5 sec.	1.8 cm.	Vac.	High
2.0 "			
8.0 "	"		"
20.0 "			
0.5	15. cm.	He.	High
2.0			
8.0	"		"
20.0			
0.5	15. cm.	He.	Low
2.0			
8.0	"	"	"
20.0			
0.5	15. cm.	Ar.	Low
2.0			
8.0	"	"	"
20.0			

Plate III
A—Glass Prism Spectrum of Mercury Induction Discharge. B—Quartz Prism Spectrum of the Mercury Induction Discharge

Conclusion

In concluding this paper I wish to express my appreciation for the guidance given by Dr. Saul Dushman of the General Electric Company, and for the able experimental assistance of Messrs. F. M. Garretson, Jr. and T. J. Radcliffe and of Dr. Carl Eckart in carrying out the experimental work. This work was started by the writer in the Research laboratory of the General Electric Co., at Harrison, N. J.

References

See unabridged pamphlet copy.

NEW LAMP REVEALS MINE GAS

A new type of electric safety lamp was recently displayed in Vienna, in which the filament is made up of a series of semi-circular loops of palladium and the bulb is stopped with a disk or porous stone. The base fits the standard lamp socket.

In a normal atmosphere, the ends of the filament show dark red. When methane gas, the deadly fire damp, is present in the air, the center of the filament becomes brilliantly incandescent, and when eight per cent or more of methane gas is present, the center of the filament continues to glow after the current is turned off.

The Measurement of Surge Voltages on Transmission Lines Due to Lightning

BY EVERETT S. LEE* and C. M. FOUST*

Associate, A. I. E. E. Associate, A. I. E. E.

Synopsis.—This paper, after referring to the work of previous investigators in the application of the photographic Lichtenberg figures to the measurement of surge voltages, describes results of additional work in this field by the authors.

Laboratory calibrations of photographic Lichtenberg figures, using the cathode ray oscillograph and the lightning generator, are shown. Data are presented relative to the accuracy obtainable with these figures as a means of measuring surge voltages.

An extension of instrument design is described in which two recording elements are used to give greater certainty of result.

Means for connecting a surge voltage recorder instrument to a transmission line by an insulator-string potentiometer are described, and calibration of the instrument with potentiometer is given up to 1400 kv.

Specimen field records of surge voltages up to 2000 kv. are shown.

* * * * *

INTRODUCTION

THE results of continued recent study and use of the photographic Lichtenberg figures as a means of measuring voltages of short time duration in the order of microseconds, particularly surge voltages on transmission lines due to lightning, are creating a confidence in these figures which is gratifying both to the engineer who is called upon to make such measurements and to the engineer who uses the results in design and application. It was in 1777 that Dr. G. C. Lichtenberg [1]

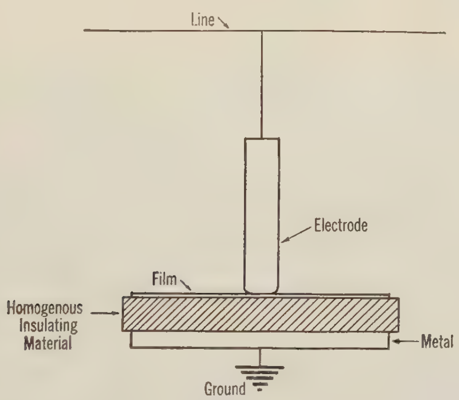


FIG. 1—ARRANGEMENT OF ELEMENTS FOR PRODUCING PHOTOGRAPHIC LICHTENBERG FIGURES

Directly connected recorder

first described the figures in sulphur dust caused by the presence of a charged electrode. In 1888, Trouvelet[2] and Brown[3] showed that the same figures would be produced on a photographic plate. Several investigators[4, 5, 6] have since devoted much time to studying the nature of these figures, although at the present time their exact mechanism is still an uncertainty.

But it remained for Mr. J. F. Peters[7] in 1924 to suggest the application of these figures to the measurement of surge voltages and to develop a suitable instrument based on this application which he called the klydonograph. In June, 1925, Messrs. Cox and Legg[8] presented before the A. I. E. E. the results of field tests with this instrument and described extended developments in the instrument design. In September, 1926, Mr. K. B. McEachron[9] presented before the A. I. E. E.

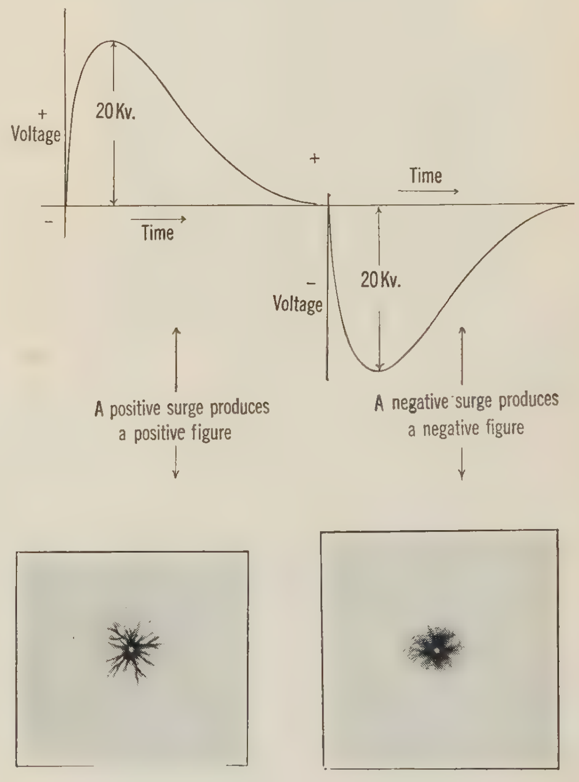


FIG. 2—SHOWING APPEARANCE OF POSITIVE AND NEGATIVE PHOTOGRAPHIC LICHTENBERG FIGURES PRODUCED BY POSITIVE AND NEGATIVE SURGE VOLTAGES OF SAME MAGNITUDE AND WAVE SHAPE

Directly connected recorder

the results of a most detailed study of the calibration of the photographic Lichtenberg figures using the Dufour cathode ray oscillograph as the means for determining with certainty the wave shape of the impressed voltage. Thus the discovery made 150 years ago has recently been applied to advantage.

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*Both of General Engineering Laboratory, General Electric Co., Schenectady, New York.

1. For references, see Bibliography.

To be presented at the Winter Convention of the A. I. E. E., New York, N. Y., Feb. 7-11, 1927.

To the work previously described, this paper contributes additional correlative data, describes an extension of instrument design, and shows that the art has advanced to a stage where surge voltages on transmission lines in the order of 2,000,000 volts may be recorded with a reasonable degree of accuracy.

General

As now used, the klydonograph or surge voltage recorder consists of an electrode bearing upon the emulsion side of a photographic film or plate which rests on the smooth surface of a piece of homogeneous insulating material, as shown in Fig. 1. If the electrode is connected to the line side of a circuit, and the insulation connected to the ground side through a metal plate, and a positive surge voltage of, say, 20 kv. maximum is impressed from line to ground, a positive figure as shown in Fig. 2 will be found on the photographic film after development. If, with the same connections, a negative surge voltage of, say, 20 kv. maximum is impressed from line to ground, a negative figure, as shown in Fig. 2, will be found on the photographic film after development

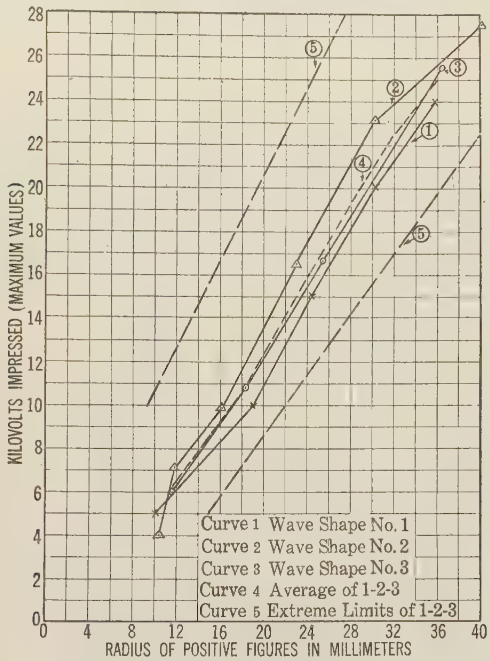


Fig. 3—Calibration Curves for Surge Voltage Recorder

Insulation, varnished paper 1/8 in. thick
Electrode, brass, 1/8 in. diameter, rounded spherically
Film, Eastman No. 152

It has been found that figures will be produced even though the time duration of the impressed voltage is only a fraction of a microsecond, also that the size (radius) of the figure is a function of the magnitude of the maximum value of the impressed voltage, while the shape and configuration of the figure is a function of the wave shape of the impressed voltage. The problem of the instrument engineer therefore becomes one of deciphering the figures into terms of voltage and wave shape.

Magnitude of Voltage

The calibration of Lichtenberg figures for a given instrument to determine magnitude of voltage is obtained by impressing voltages of different values and observing the size of the resulting figure. This can be done for as wide a range of wave shapes as are available.

Table I and Fig. 3 of this paper give results of the authors' calibrations obtained on a film-type instrument with varnished paper insulation and a brass electrode ⅛ in. in diameter rounded spherically. The wave shapes varied from one-half cycle of a sine wave at 60 cycles (wave shape No. 1) to surge voltages rising to their maximum value in two microseconds (wave shape No. 2) and in four microseconds (wave shape No. 3). The surge voltages were impressed from sections of a 500-kv. rectifying type lightning generator (Fig. 4), the circuit for wave shape No. 2 being as shown in Fig. 5 and for wave shape No. 3, as shown in Fig. 6. The wave shapes were determined by Dufour cathode ray oscillograph Figs. 7 and 8. Wave shape No. 2 is shown in Fig. 9. Wave shape No. 3 is shown in Fig. 10.

When calibrating the surge voltage recorder or when photographing the wave shapes with the cathode ray oscillograph, these instruments were connected between ground and the various voltage taps as shown in Figs. 5 and 6. The magnitude of the voltage was measured by sphere spark gap similarly connected.

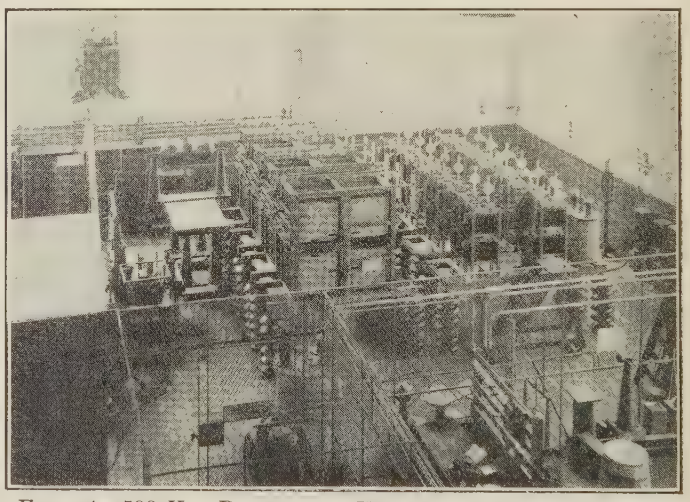


Fig. 4 –500-Kv. Rectifying Type Lightning Generator used as Source for Surge Voltages in Studying Photographic Lichtenberg Figures

The cathode ray oscillograph used with this generator is located in the sheet-iron house at the left of the photograph

Fig. 11 shows a set of positive and negative figures for 5, 10, 15 and 20 kv. taken with wave shape No. 2. It is from such figures as these that the calibration curves are obtained. The radius of a positive figure is measured from the figure center to the most distant streamer tip.

TABLE I
CALIBRATION OF POSITIVE PHOTOGRAPHIC LICHTENBERG FIGURES

60-Cycle Wave Shape—Wave Shape No. 1

Kv. impressed (max. values)	Number of figures	Positive figures average radius mm.	Average deviation from mean. Per cent plus and minus	Maximum deviation from mean. Per cent plus and minus
5	35	10.3	12	45
10	34	19.0	5	16
15	36	24.3	5	15
20	36	30.2	8	37
24	31	35.6	5	12 disregarding slips 125 regarding slips
Two-Microsecond Wave Front—Wave Shape No. 2				
4	29	10.6	9	25
7.2	39	11.9	22	60
10	36	16.3	10	35
16.6	36	22.8	10	26
23.2	36	30.4	5.5	19
27.6	37	40.3	14	26
Four-Microsecond Wave Front—Wave Shape No. 3				
5.95	36	11.8	12	41
10.75	35	18.3	6.5	20
16.7	36	25.3	5.3	15
25.6	36	36.4	6.2	24

Average Deviation For All of Above Wave Shapes

Kv. impressed (max. values)	Number of figures	Average deviation from the mean. Per cent plus and minus	Maximum deviation from the mean. Per cent plus and minus
5	100	13.7	32
10	105	8.5	31
15	108	7.2	28
25	104	10.2	33

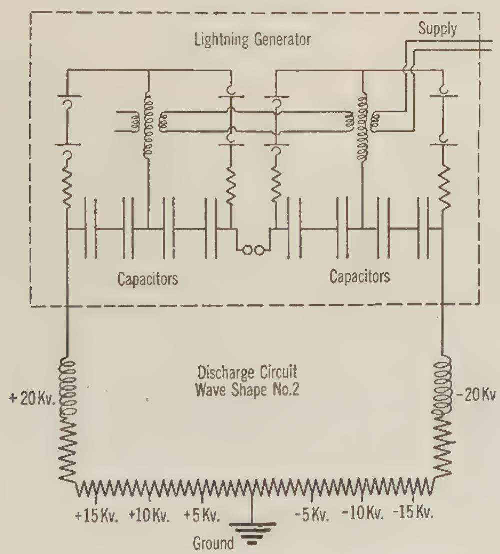


FIG. 5—ARRANGEMENT FOR PRODUCING WAVE SHAPE NO. 2

The capacitors of the lightning generator discharge through the inductance and resistance shown in the external discharge circuit, in which the balanced arrangement of circuit constants with respect to the grounded point eliminates local oscillations

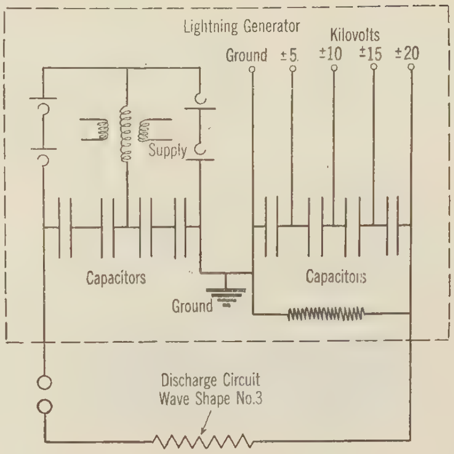


FIG. 6—ARRANGEMENT FOR PRODUCING WAVE SHAPE NO. 3

The capacitors of the lightning generator on the left, discharge into the capacitors on the right through the resistor shown in the external discharge circuit

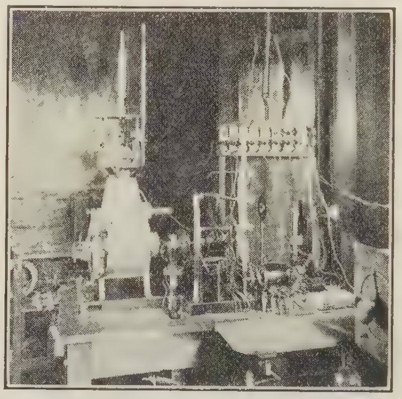


FIG. 7—THE DUFOUR CATHODE RAY OSCILLOGRAPH, SIDE VIEW

The timing switch shown at the right of the oscillograph is for low-speed work. The timing switch used to discharge the lightning generator when calibrating the surge voltage recorder is of high-speed type of special design, not shown

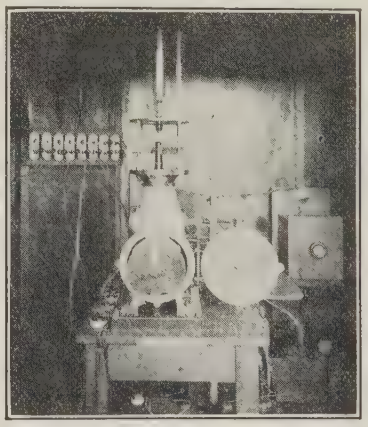


FIG. 8—THE DUFOUR CATHODE RAY OSCILLOGRAPH, FRONT VIEW

Referring to Table I, it is seen that the average deviation from the mean for 100 figures on the three wave shapes investigated at the different voltages is within ± 15 per cent, while the maximum deviation from the mean is in the order of ± 30 per cent.

These results are shown graphically in Fig. 3. For any voltage all figures obtained on 100 measurements were within the extreme limits as shown. These limits are determined by one figure out of one hundred, and are quite outside of the values which may be

reasonably expected from the average values shown. It appears that an accuracy of 25 per cent can be reasonably expected from any single measurement made with these figures. Where several figures of somewhat the same size are obtained under similar conditions, the agreement of these among themselves permits a more exact interpretation.

Messrs. Cox and Legg, in Fig. 39 of their paper[8], show a calibration curve for an experimental model of a film-type klydonograph. The wave shapes impressed varied from 25- and 60-cycle a-c. sine wave, to a surge voltage which attained its maximum value in five microseconds, the latter surges being obtained from a given network and their shape determined by calculation. The magnitude of the voltage was determined by sphere spark gap.

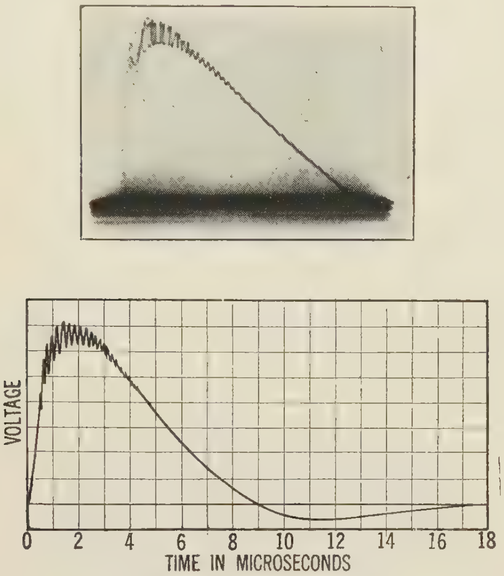


Fig. 9

(Above)—Cathode Ray Oscillogram of Wave Shape No. 2

(Below)—Cathode Ray Oscillogram of Wave Shape No. 2 Transcribed to Rectangular Coordinates

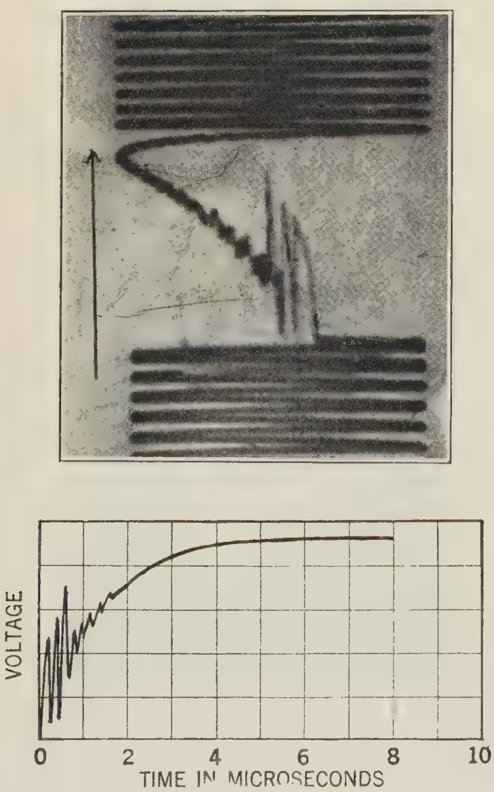


Fig. 10

(Above)—Cathode Ray Oscillograph of Wave Shape No. 3

(Below)—Cathode Ray Oscillogram of Wave Shape No. 3 Transcribed to Rectangular Coordinates

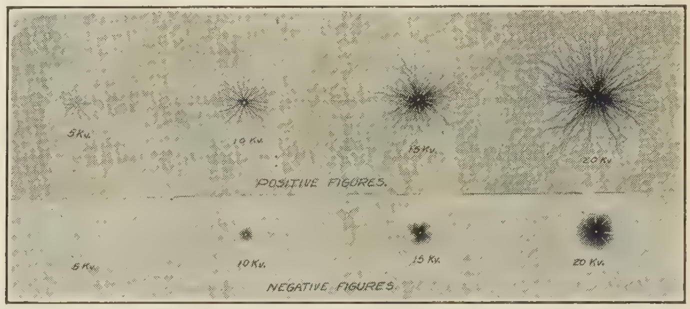


Fig. 11—Positive and Negative Lichtenberg Figures for Different Voltages. (Wave Shape No. 2)

McEachron, in Fig. 7 of this paper[9], shows calibration curves for Lichtenberg figures obtained with Eastman's super-speed portrait films, placed on a glass plate, and using a cylindrical brass electrode one cm. in diameter with square edges. The shape of the impressed voltage was determined by Dufour cathode ray oscillograph and the magnitude by sphere spark-gap. The range of wave shape was from a long wave wherein 22 min. were required to reach a maximum value of 25 kv., to a short wave where the time to reach maximum value was 0.1 microsecond.

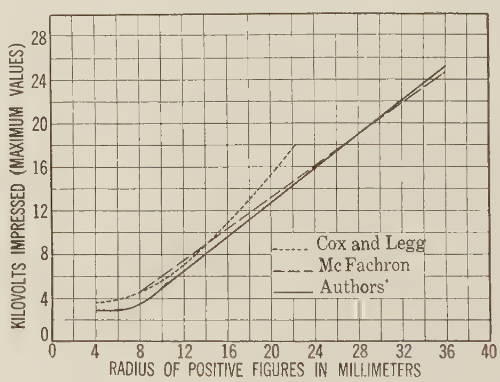


Fig. 12—Calibration Curves of Surge Voltage Recorders for Positive Lichtenberg Figures

Cox and Legg, Bibliography Item 8, Fig. 39
McEachron, Bibliography Item 9, Fig. 7
Authors' Fig 3 (average curve)

The results of the calibrations reported by Messrs. Cox and Legg, and McEachron, are shown combined with the authors' in Fig. 12. These results show remarkable agreement for the work of different observ-

ers in different laboratories with different instruments and circuits, and give added weight and certainty to the calibration of the Lichtenberg figures as regards magnitude of voltage.

Wave Shape of Impressed Voltage

In studying surge voltages, the wave shape as well as the magnitude is of importance, for on this depends the

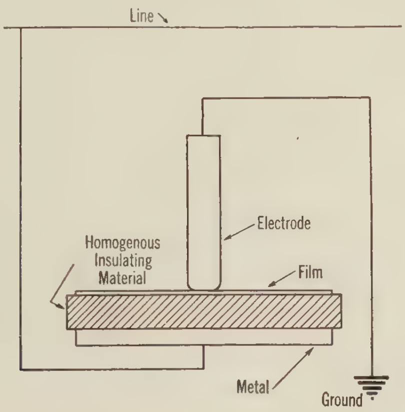


Fig. 13—Arrangement of Elements for Producing Photographic Lichtenberg Figures
(Oppositely connected recorder)

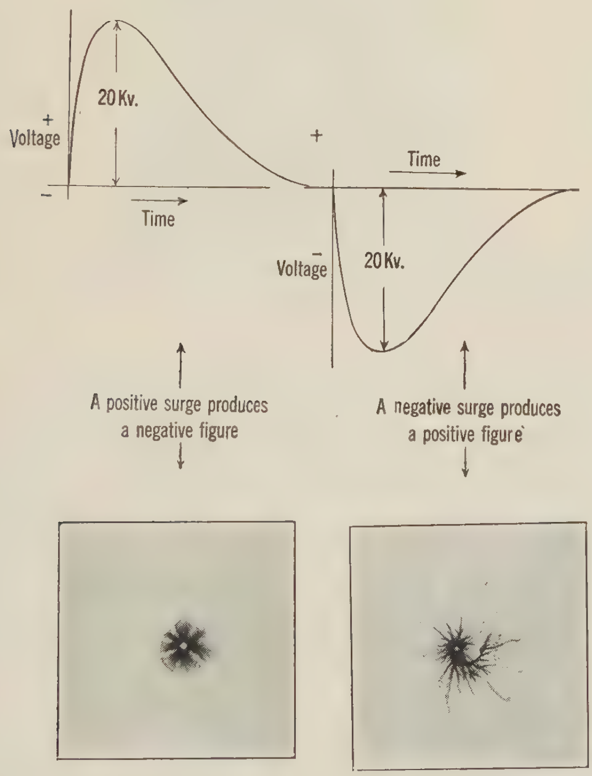


Fig. 14—Showing Appearance of Negative and Positive Photographic Lichtenberg Figures Produced by Positive and Negative Surge Voltages of Same Magnitude and Wave Shape
(Oppositely connected recorder)

duration of the voltage. At the present time, the determination of the wave shape from the Lichtenberg figure characteristics is not as definite or as certain as the determination of the magnitude from the figure size and herein there is room for added study. At the present time the figures recorded with unknown wave shapes can be compared with figures recorded with known wave shapes as determined by cathode

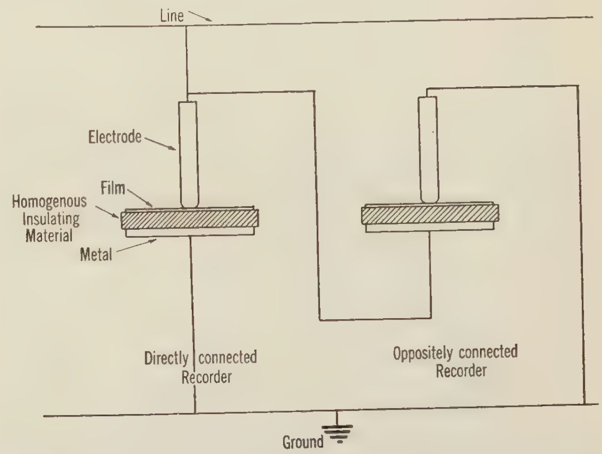


Fig. 15—Arrangement of Elements for Producing Both Positive and Negative Figures for any Surge Voltage

ray oscillograph. This allows prediction of the time duration to within a general order, but not with the exactness required. The work by McEachron in this regard, as shown in Fig. 5 of his paper[9], wherein he

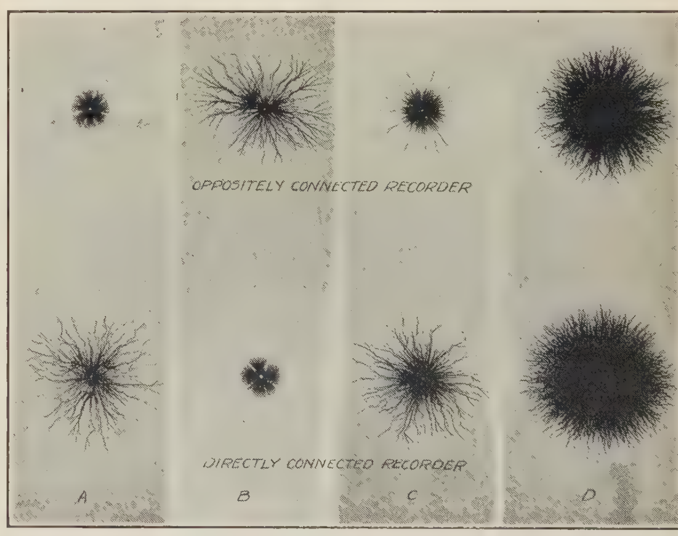


Fig. 16—Photographic Lichtenberg Figures Obtained with Two-Recorder Type Instrument

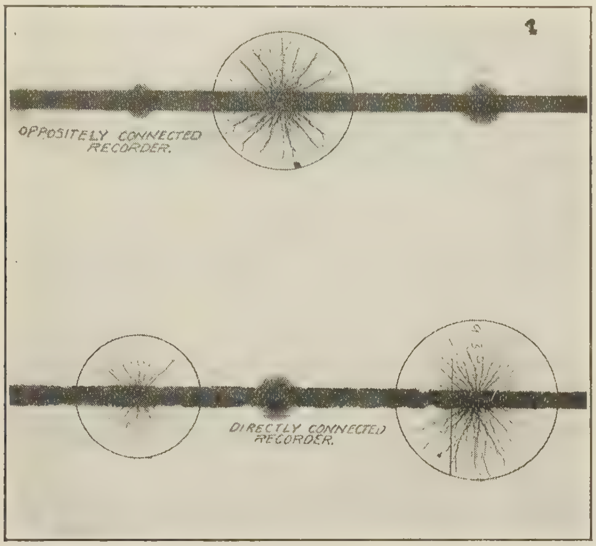
A—Positive surge voltage 20 kv. maximum
B—Negative surge voltage 20 kv. maximum
C—Oscillatory surge voltage 20 kv. highly damped
D—Oscillatory surge voltage 20 kv. slightly damped

designates the figures as Type I, Type II, and Type III, is to be commended. Further study along these lines tending towards greater exactness in the interpretation of figure characteristics is desirable.

Directly and Oppositely Connected Recorders

From Fig. 11 it is clearly evident that the negative figures are quite inferior to the positive figures for purposes of voltage measurement since for a given voltage

they are less than half the size of the positive figure; also McEachron has shown[9] that the negative figures present a greater deviation for differing wave shapes. There is also another serious objection which is that when the instrument with a moving film is connected to a transmission line with normal voltage continuously impressed, the width of the band produced by the line



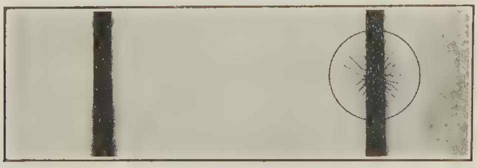
A B C

Fig. 17—Figures Obtained with Two-Recorder Type Instrument Showing Line Voltage Band

A—Positive surge voltage 13 kv. maximum (20 mm.)
B—Negative surge voltage 14 kv. maximum (22 mm.)
C—Positive surge voltage 17 kv. maximum (25 mm.)

The circles shown are drawn with the figure center as a center, and with the circumference touching the most distant streamer tip. The radius of this circle is the measure of the magnitude of the voltage

The line voltage band is from 60-cycle source of 2.84-kv. maximum value



A B

Fig. 18—Photographic Lichtenberg Figures Obtained with Two-Recorder Type Instrument Showing Hidden Negative Figure

A—Directly connected recorder B—Oppositely connected recorder

Negative surge voltage 9.0 kv. maximum. The negative figure is hidden under the line voltage band. Its presence is indicated by the full-size positive figure on the oppositely connected recorder

The line voltage band is from 60-cycle source of 3.0-kv. maximum value

voltage (see Figs. 17 and 18) is enough to hide negative surges up to values as high as 2.3 times normal line voltage and to give uncertainty to values somewhat above this. This would result in erroneous conclusions as regards the number of negative surges recorded.

To overcome these objections, Mr. Foust conceived the idea of connecting two recorders in parallel with the connections of one opposite from that of the other, thus insuring a large positive figure for every surge. Referring again to Fgis. 1 and 2, the results of directly connecting the recorder to the line are shown. If, however, the recorder is connected oppositely, that is, the electrode to ground and the metal plate to the line, as in Fig. 13, the positive surge will record a negative figure and the negative surge will record a positive figure as in Fig. 14.

If an instrument is made up with two recorders, one connected directly and one connected oppositely, as shown in Fig. 15, then all surges, positive or negative, can be measured from the positive figure. In addition, oscillatory surges will be more clearly recorded, and negative surges completely hidden by the line-voltage band will be shown distinctly as positive figures. These features are shown in Figs. 16, 17 and 18.

Fig. 19 shows an instrument of the two-recorder type. It uses an Eastman film eight feet long and eight inches wide as standard with "Cirkut Outfits." It is driven by a clock at a rate of ½ in. per hour, so as to give a continuous record for eight days. Timing is obtained by photographing the hour numbers on the film.

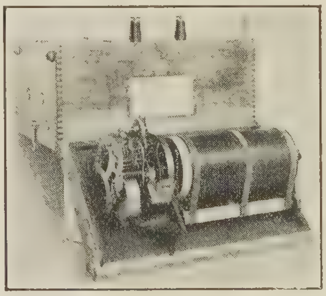


Fig. 19—Surge Voltage Recorder. Two-Recorder Type Instrument

This construction largely excludes polyphase instruments, because of constructional difficulties, but the obvious advantages of having all figures available as positive figures is so great as to accept this condition. It is felt that the application of this idea represents a real extension of the use of the Lichtenberg figures and results already obtained in the field show its merits. For example, out of 103 surges measured on three different transmission systems, 31 were of positive polarity, 26 were of negative polarity, and 46 were oscillatory.

Connection to Transmission Line

The voltage range of the instrument shown in Fig. 19 is from 2.8 to 25 kv. maximum. Above 25 kv. maximum, so-called "slips" occur in the figures as shown in Fig. 20, for which condition calibration curves do not apply. The arcover of this instrument on a two-microsecond wave, wave shape No. 2, Fig. 9, is 35 kv. maximum. Thus, some provision must be made for connecting the instrument to transmission lines up to values where the normal maximum voltage to ground is 180 kv. maximum for a 220-kv., 3-phase line, and where

the maximum values of surges may be ten times this value.

Messrs. Cox and Legg[8] describe an electrostatic potentiometer and antenna coupling. The authors have investigated and used insulator coupling. Of the various schemes proposed for such connection, that shown in Fig. 21 has been recently used in 27 installations and has been found to be simple, reliable, and easy to calibrate. The instrument is connected in parallel across several insulators of an insulator string with added protection over the line insulation as desired. The instrument is placed in a sheet metal housing, Fig. 22, equipped with suitable entrance bushing and automatic grounding device when the door is opened. The door is equipped with a padlock. This housing protects the instrument from the weather and insures safety against tampering. The metal housing also acts as an electrostatic shield to eliminate stray field effects.

Fig. 20—Photographic Lichtenberg Figures Above the Instrument Range

Positive surge voltage 33 kv. maximum wave shape No. 2

The black lines clearly evident in the positive figure (below) are commonly called "slips" and their presence indicates the figure to be of uncertain calibration. However, such figures can be stated with certainty to be above a given voltage value depending upon the instrument design

The negative figure (above), though symmetrical and appearing to be suitable for voltage measurement, nevertheless is not so in this range because of the great variation in figure size with wave shape. (See bibliography item 9, Figs. 6 and 7)

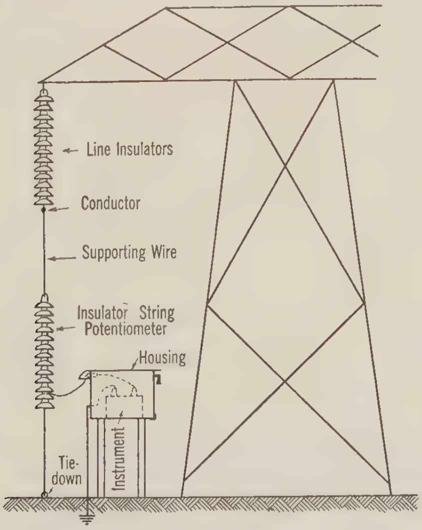


Fig. 21—Arrangement for Connecting Surge Voltage Recorder Instrument to Transmission Line

Fig. 23 shows the arrangement of housing, insulator string, and connecting leads for a field installation.

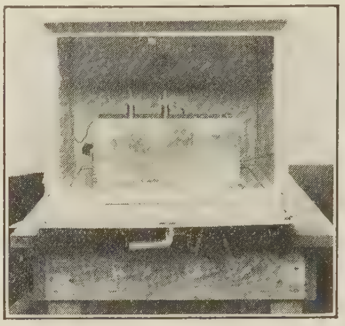


Fig. 22—Sheet Metal Housing for Surge Voltage Recorder

It is important to have the instrument connecting leads short, preferably not longer than five feet. From Fig. 24 it is seen that the figure size decreases considerably with a longer lead, and if the instrument is used with leads of different length than that with which it is calibrated, the resulting error is large.

Adjustment of Insulator String Potentiometer

The adjustment of the insulator string potentiometer is made by adding a sufficient number of insulator units in series with the normal line insulators to give adequate protection, and to provide enough insulator units across which the surge voltage recorder instrument may be paralleled to obtain a satisfactory line voltage band. This procedure may be carried on in the laboratory by impressing normal voltage at normal frequency across the entire insulator string with the surge voltage recorder in position.

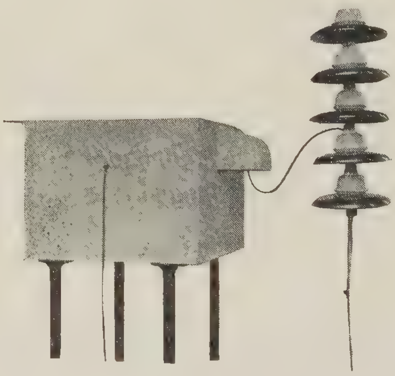


Fig. 23—Illustration of Field Set-Up of Insulator String Potentiometer and Surge Voltage Recorder in Sheet Metal Housing

Table II gives the number of insulators which have

been used successfully in the insulator string for different line voltages.

TABLE II

Line voltage between conductors three-phase kv.	No. of insulators line insulation	No. of insulators instrument string potentiometer	No. of insulators in parallel with instrument (included in col. 3)
66	4	9	2
110	8	13	2
140	10	15	2
220	14	20	4

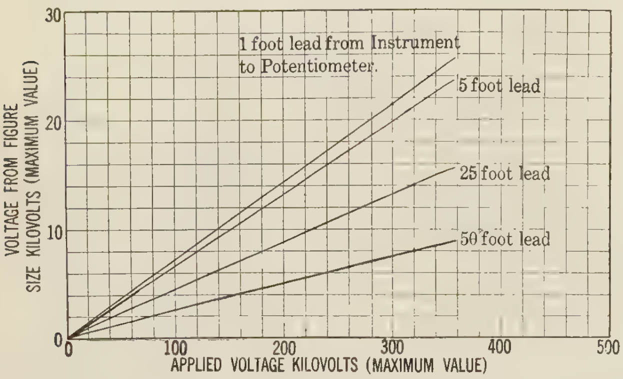


FIG. 24—CALIBRATION OF SURGE VOLTAGE RECORDER AND POTENTIOMETER TO SHOW EFFECT OF LENGTH OF INSTRUMENT LEAD

CALIBRATION OF INSULATOR STRING POTENTIOMETER

The multiplying factor of the potentiometer can be calculated for normal voltage and frequency from the data obtained in adjusting the potentiometer string.

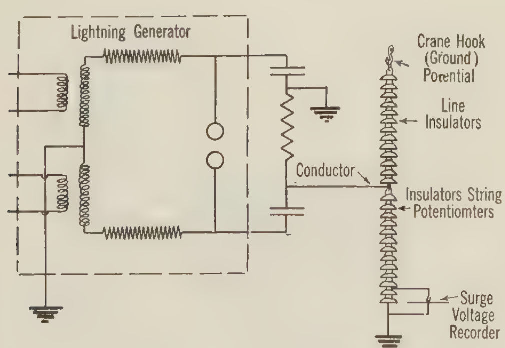


FIG. 25—ARRANGEMENT FOR PRODUCING SURGE VOLTAGES FOR CALIBRATION OF INSULATOR STRING POTENTIOMETER

For example, a 110-kv. line has a maximum value of voltage to ground of 90 kv. If the line-voltage band is three kv., then the potentiometer multiplying factor is 30.

The question then arises: Does this ratio hold for surge voltages? To answer this question, surge voltages were impressed across an insulator string potentiometer whose 60-cycle multiplying factor was 60. This was a string of twenty insulators, four of which were in parallel with the surge voltage recorder. The source of the surge voltages was a lightning generator of the non-rectifying type discharging into an external circuit as shown in Fig. 25. This circuit had to be used rather than the circuits as shown in Figs 5 and 6 in order to attain the requisite voltage. The magnitude of the voltage was determined by sphere spark gap. The time of rise of the surge voltage to its maximum value calculates to be in the order of a fraction of a microsecond.

The results of the calibration of the potentiometer up to 1,400,000 volts are shown in Fig. 26. These results show a generally decreasing multiplying factor from the higher to the lower voltages. At the higher voltages the multiplying factor is practically the same as that obtained with 60-cycle voltage.

Results of tests with circuit arrangement with the rectifying type of lightning generator (Fig. 5) to give a wave similar to that shown in Fig. 9 are also shown in Fig. 26. Tests were made with the insulator string potentiometer both dry and wet with spray. These were at the highest voltage which could be obtained

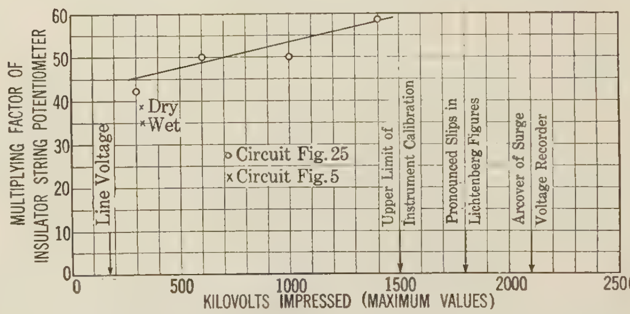


FIG. 26—SURGE VOLTAGE CALIBRATION OF INSULATOR STRING POTENTIOMETER

Potentiometer for 220-kv., three-phase line
Number of insulators in string. 20
Number of insulators paralleled with the surge voltage recorder, 4
Instrument, as shown in Fig. 19 housed in housing as shown in Fig. 22.
Set-up as shown in Fig. 23

with this generator for this type of work. The results seem to agree quite well with the non-rectifying type of lightning generator at the same voltage. The results of tests made with the insulator string when dry and also when wet show that for surge voltages the voltage distribution is practically unchanged under these two conditions. This is different from the condition at 60 cycles where at least at lower voltages the differences between the distributions wet and dry are greater.

From the calibration of Fig. 26, for figures showing an instrument voltage of 25 kv., the surge voltage on the line is 1500 kv. Figures with slips would indicate surge voltages from 1500 kv. to 2100 kv. Film arcover at 35 kv. on the instrument would indicate surge voltages on the line of 2100 kv. or over.

The results of these calibrations indicate that surge voltages up to ten times normal maximum value, line to ground, on a 220-kv. line can be measured with considerable certainty as regards magnitude.

Specimen Field Records

On Fig. 27 are shown some Lichtenberg figures obtained on a transmission line installation. The surge record is from 3 p. m. until 10 a. m. of the next day. During this time there were lightning storms in the vicinity of the line. It is clearly seen that these figures have the same characteristics as those produced with laboratory equipment. (The circles are drawn for voltage measurement, see Fig. 17.) The figures on the left and right are interpreted to be from oscillatory surges of highly damped nature, such as shown in Fig. 16c which is known to be from an oscillatory surge voltage. The oscillatory nature of these surges is derived from the presence of both positive and negative Lichtenberg figures on both recorders. The middle figure indicates a unidirectional surge voltage of negative polarity such as shown in Fig. 16b.

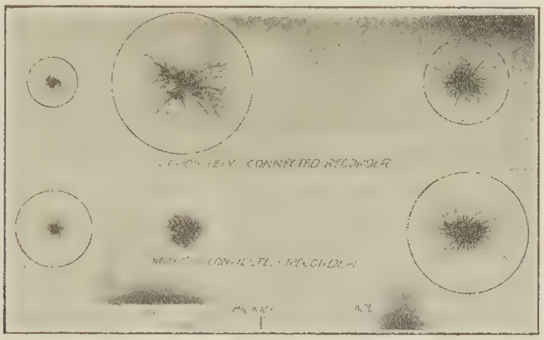


Fig. 27—Lichtenberg Figures Obtained on a Transmission Line Installation during a Lightning Storm

It is noted that there is no line-voltage band upon the film. This sometimes occurs and it is thought that this is due to the variation in voltage distribution across the insulator string potentiometer at normal line voltage and frequency.

Fig. 28 shows a photographic record of surge voltages obtained on a 220-kv., three-phase power transmission line, using a surge voltage recorder of the two-recorder type (Fig. 19) with an insulator string potentiometer as described above. The normal maximum value of the voltage to ground is 180 kv. and the multiplying factor of the potentiometer was 60. The record shown is from 11 a. m. on one day to 2 p. m. the day following. The line-voltage bands show when the line voltage was on and off during this period.

The record shows distinctly a high surge voltage at 4:20 p. m. on Friday and the weather reports indicate severe lightning in the vicinity of the installation at this time. The loss of the line-voltage band some thirty minutes before this surge shows that the line was de-energized at 3:50 p. m. A close examination of the original film reveals a surge at 4:03 p. m. but this is not distinguishable from the print. The figure obtained at 4:20 p. m. on the oppositely connected recorder is a positive "slip" (see Fig. 20) and therefore represents a voltage of negative polarity on the instrument of between 25 kv. and 35 kv. Using a potentiometer multiplying factor of 60, this figure represents a surge voltage on the line of from 1500 to 2100 kv. The corresponding figure on the directly connected recorder is predominently negative. Since some positive figure characteristics are discernible on the directly connected recorder, however, the surge must have been oscillatory and of a highly damped nature (see Fig. 16) with a first half-cycle of negative polarity and the second of positive polarity and very much lower voltage.

At 10:30 p. m. on the same day another surge was recorded. A lightning storm was in progress at this time and the line excitation had been removed about fifteen minutes before this surge. Positive figures were obtained on both recorders. The figure on the oppositely connected recorder indicates an initial half-cycle of negative polarity of 780 kv. The figure on the directly connected recorder indicates the second half-cycle to be of positive polarity of 270 kv.

The weather records for Saturday morning show another lightning storm in progress. The surge record reveals two surges, one at 8:11 a. m. and one at 8:18 a. m., the line having been de-energized at 8:11 a. m. From the print, these two surges are not so clearly distinguished, though from the original film the record is clear. The figure obtained at 8:11 a. m. on the directly connected recorder is of positive characteristics and on the oppositely connected recorder of negative characteristics. The line surge was therefore unidirectional and positive in polarity. The figure on the directly connected recorder is a positive "slip" and therefore indicates a line voltage of between 1500 and 2100 kv.

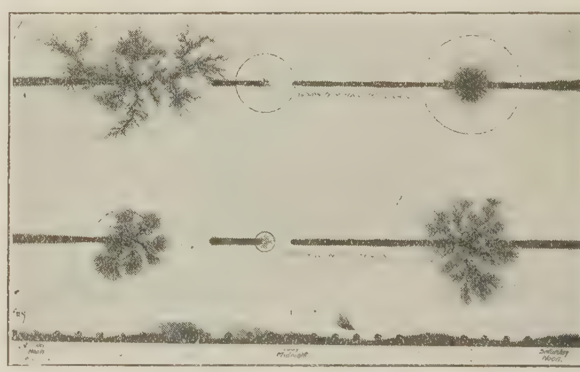


Fig. 28—Specimen Record of Surge Voltages on a Transmission Line during Lightning Storms

The figure obtained at 8:18 a. m. is positive on the oppositely connected recorder. The instrument voltage corresponding to this figure is 21.5 kv. and this gives a line voltage of 1290 kv. of negative polarity.

This specimen record shows how the figures may overlap on the slowly moving film when the surges occur in quick succession. Even under these conditions, however, it is generally possible to analyze the figures with considerable accuracy when the original film is

used and when the figures from the two recorders are available.

Practically all figures obtained on transmission lines have been of the type II class[9], and may be placed, therefore, within the wide range of wave fronts which vary roughly from that of a slow 60-cycle wave to a surge which comes to its maximum value in a fraction of a microsecond's time.

In connection with the surge voltage values obtained from the figures shown on the specimen record (Fig. 28), it is interesting to note that they compare favorably with the laboratory results of insulator flashover tests. The value 1800 kv. for the lightning sparkover of a 14-unit insulator string given by Mr. Peek[10] seems to be close to the upper limit of voltages actually measured on the line by means of the recorders.

SUMMARY

It has been shown that surge voltage recorders using the positive photographic Lichtenberg figures have given essentially the same calibration data under a variety of conditions; also that the accuracy of such an instrument is in the order of 25 per cent, with a somewhat better value possible for those measurements wherein several similar observations may be obtained.

An extension of instrument design has been described wherein two recorders are used together, which allows the use of the positive figure as a voltage measure of all surge voltages, thus insuring greater certainty of result. A more comprehensive analysis of the figure characteristics is also possible, since both positive and negative figures are available.

A means of connecting the surge voltage recorder to a transmission line of higher than instrument voltage has been described which has been proved in service to be simple, reliable, and easy to calibrate. Calibration data are presented to show that with such connection, reasonable accuracy may be obtained in recording voltages up to values in the order of 2000 kv. A specimen record of such voltages obtained in the field is shown.

The records which can be obtained from surge voltage recorder instruments connected as desired along a transmission line will allow the facts regarding surge voltages on transmission lines to be determined with reasonable exactness.

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ASTRONOMICAL CLOCK CONTROLS STREET LIGHTS

The new street lighting system of the city of St. Louis will be turned on and off at sunset and sunrise without the aid of human hand.

An astronomical clock which automatically sets its alarm for the seasonal variations in night and day is the nerve center of the control apparatus with which these automatic substations are being equipped.

This sensitive timepiece is motor-wound and requires no more than the occasional cleaning which every watch needs. About once a year, a slight correction might have to be made to bring the clock exactly to standard time.

The astronomical dial has two contactors on a single drum, one for morning and one for evening. When the "PM" contact engages its first position of the day, it closes and locks an electric circuit in which is wired the "master sequence" relay. This master relay in turn sets in motion a contact drum. The first of these contacts puts currents from a 13,000-volt incoming line, onto the "station bus"; that is, onto the main switchboard line of the substation. At intervals of five seconds thereafter, one contact closes. Each contact closes a branch circuit carrying part of the lighting load. In the Anne Avenue substation, which controls the first part of the new $8,000,000 system, there are seven of these branch circuits. Each has its own set of switches and protective devices, which are set to working automatically when the time switch starts the ball rolling.

When the dial reaches the "AM" contact, the master relay drum is in "AM" position. This time, however, each contact of the drum operates a relay disconnecting the branch circuits successively and automatically.

In the event of trouble on the incoming lines or on one of the distributing circuits, protective relays are provided for every kind of emergency. So long as a power source is available at the substation, the relays will keep that source connected to the station bus. When none of the incoming lines has power, the relays "kick" out the switches governing the branch circuits. In case of trouble on one of the branches, the relays again function, switching out the whole branch. If the trouble is in the apparatus at the station, an emergency set can be cut over by hand to take the position of the disabled member.

Abridgment of

A Shielded Bridge for Inductive Impedance Measurements at Speech and Carrier Frequencies

BY W. J. SHACKELTON[1]

Associate, A. I. E. E.

Synopsis.—*A shielded, a-c., inductance bridge adapted to the measurement of inductive impedances at frequencies up to 50,000 cycles is described. The bridge comprises a balancing unit and associated standards of inductance and resistance. The balancing unit has resistance ratio arms specially constructed to meet the requirements imposed by the above frequency range. The reference standard makes use of inductance coils of a new type, their cores being of magnetic instead of non-magnetic material as is usually the case. The use of such cores results in coils that are smaller and hence better adapted to assembly in a multiple shielded standard.*

The bridge is completely shielded so as to eliminate, to a high degree, errors due to parasitic capacitance currents. The shielding is also arranged so as to permit the correct measurement of either "grounded" or "balanced-to-ground" impedances. A series of diagrams is shown for the purpose of indicating the function of each part of the shielding system.

Equations expressing the errors resulting from any small residual capacitance unbalances in the resultant bridge network are given and calculations made of the balances required for the desired degree of measurement precision. Test data are presented illustrating a method of experimentally checking the residual shunt and series balances from which it is concluded that the bridge is capable of comparing two equal inductive impedances of large phase angle with an accuracy at the maximum frequency of 0.02 per cent for inductance and 1.0 per cent for resistance.

Introduction

The limitations of the ordinary unshielded bridge network as a means of making precise a-c. measurements at speech frequencies were recognized early by telephone engineers. The solution of cross-talk problems arising in connection with the use of cable circuits was found to require an exact knowledge of the capacitive balances existing between such circuits at speech frequencies. For the ready and accurate determination of the capacitances defining these balances, together with their associated conductance values, Dr. G. A. Campbell devised the "shielded balance."[2] This is a bridge network having its parts individually and collectively shielded so as to define exactly the mutual electrostatic reaction of each with respect to all other parts of the electrical system affecting the balance condition.

While the fundamental principles of the shielded balance are essentially the same for all impedance measurements, the practical application of shielding to any concrete bridge problem may vary according to the kind and range of impedances to be tested, the frequency range to be covered, and the precision required. It also presents special problems in the design and construction of several of the circuit elements. In this paper there is described a particular form of shielded bridge which has been developed to meet the conditions commonly encountered in the measurement of inductance at speech and carrier frequencies. The facts leading to the detailed construction are discussed and some experimental data given to illustrate the performance of the bridge.

1. Development Engineer, Bell Telephone Laboratories, Inc., New York, N. Y.

2. G. A. Campbell: The Shielded Balance, *Electrical World and Engineer*, April 2, 1904, p. 647.

Presented at the New York Regional Meeting of the A. I. E. E., New York, N. Y., Nov. 11-12, 1926.

General Features

A simple schematic diagram of the bridge circuit is shown in Fig. 1. Physically, the apparatus is grouped into three separate units, one comprising the standards of inductance, one the resistance standard and the third, the remaining parts of the circuit. The last assembly constitutes what may be considered the balance element of the system, by means of which the unknown and standard impedances are compared. Figs. 2 and 3 show the arrangement of the parts in this unit. Fig. 4 illustrates the appearance of the standard inductance unit and Fig. 5 shows how the units are associated when a test is being made. The thermocouple milliammeter indicates the total effective test

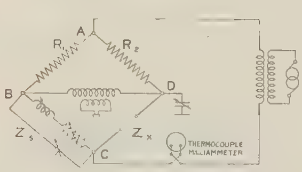

Fig. 1—Schematic Diagram of Bridge Circuit

current applied to the bridge and forms a means of determining when this current has been adjusted to the desired value.

In operation, the air condensers are first adjusted to produce an initial or zero balance of the residual electrostatic capacitances of the apparatus. Aside from the initial balancing, the operation of the bridge follows the usual practise; that is, the standards of inductance and resistance are alternately adjusted until the balance detector indicates a condition of zero potential difference at every instant between the bridge points to which it is connected. The inductance and resistance values as indicated in the standard arm are then equal (within the precision limits of the

bridge) to the corresponding constants of the unknown impedance.

Purpose of Shielding

The principal difficulties in attaining a satisfactory degree of precision in inductance measurements at relatively high frequencies by means of unshielded bridges are those due to the presence of residual or stray admittances existing between the bridge parts or from them to ground. All these parts have quite appreciable surface dimensions and when exposed at the usual separations to each other or to ground, have corresponding direct and grounded admittances. Leads to the source of testing current and to the balance detector also introduce rather large admittances. In a bridge intended for rapid operation, the parts subject to manipulation must be arranged compactly and conveniently to the operator. This makes it impracticable to isolate them sufficiently to make the admittance values between these parts and between them and ground (the operator being considered to be at ground potential) negligibly small.

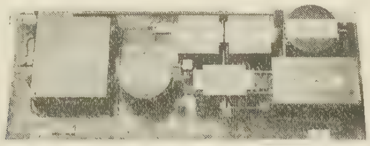

Fig. 2—Balance Element of Shielded Bridge

Rear view of panel removed from case

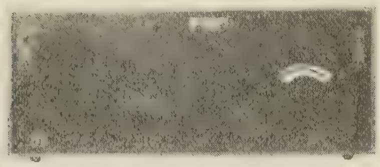

Fig. 3—Balance Element of Shielded Bridge

Front view of panel and case

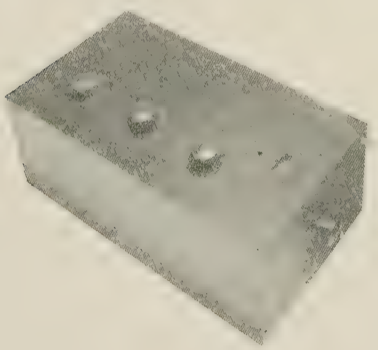

Fig. 4—Inductance Standard

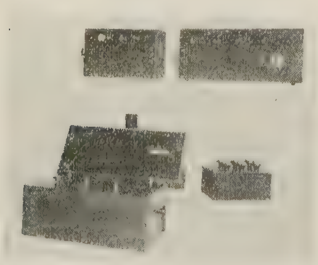

Fig. 5—Shielded Bridge Connected to Vacuum Tube Oscillator and Heterodyne Detector

To make the matter more concrete, there is shown in Fig. 6 a schematic diagram with possible positions of some of the more important of these admittances indicated as at C_1, C_2, etc.

The distribution and value of these admittances are functions of the bridge surroundings and of the connections to it. Hence they are indefinite and variable. In the bridge being described, however, the shielding used affords a means of definitely fixing and controlling the various inter-circuit capacitances. Consequently, such variations cannot take place, and the bridge measurements are satisfactorily precise.

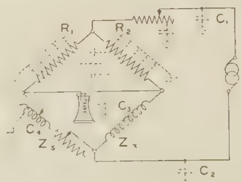

Fig. 6—Bridge Circuit with Stray Admittances

Shielding System Used

It is felt that the merits of the particular shielding system adopted for this bridge can best be brought out by showing, step by step, the reasons for using each of its elements.

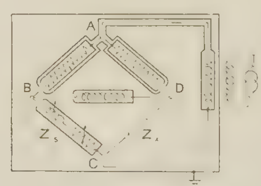

Fig. 7—Shielded Bridge Circuit Showing Location of Ground Admittance

The first step is to simplify, for further treatment, the initial residual capacitance network of the unshielded circuit. This is done by providing individual shields for each part of the circuit that it is desired to have function as an independent unit. Such shields can be connected to one of the terminals of the part enclosed and thus there is substituted, from the standpoint of terminal-to-terminal characteristics, a definite and invariable condition in place of that which was previously a function of the relation of the part to its surroundings. For example, as shown in Fig. 7, shields would be placed around the resistance coils forming the ratio arms R_1 and R_2 and connected to the junction point A of the system, one enclosing the elements of the standard

impedance Z_S and another around the source of testing current and connected at C; likewise, one around the detector is connected at D.

Generally it will not be found convenient to shield the current supply apparatus, especially if this is a power driven generator. Also, to promote greater flexibility in respect to testing with a wide range of frequencies, it will often be desirable to substitute one source of current for another and likewise one detector for another. The shielding of this apparatus should therefore be reduced to a minimum. This is readily effected by making both the supply and detector branches of the bridge one of the windings of a transformer. This winding can be electrostatically shielded without affecting its transformer action and then any desirable source of current supply or any type of detector can be magnetically coupled with it.[3]

In general, the unknown impedance will have capacitances to ground and the effect of these will be properly included in the measurement only when certain conditions as determined by the nature of the apparatus are fulfilled. From this standpoint the impedances usually encountered are of three general classes: (1) Those having ground admittances negligibly small in comparison with the direct terminal to terminal admittance; (2) those having appreciably large admittances to ground approximately balanced with respect to the two test terminals; (3) those having one terminal directly grounded, the other having an appreciably large ground admittance.

In measuring apparatus of the first type it is evident that since in connecting it to the bridge circuit no additional ground admittances are introduced, the balance between those previously existing can be made without reference to the test impedance. The connection of an impedance of either of the other types will, however, introduce additional ground admittances into the bridge system, which, unless precautions have been taken, may cause the result to be something other than that which is wanted. To obtain the desired test of an impedance having balanced admittances to ground the bridge terminals to which it is connected must likewise be balanced with respect to ground potential; that is, ground potential must be at the mid-point of the unknown impedance arm. If the only admittances to ground of the bridge system are those of the junction points (as is the case in Fig. 7), the potentials of these points with respect to ground are entirely determined by these admittances. To make any two points such as the terminals of the unknown arm have equal potentials to ground, it is sufficient to concentrate all of the ground admittances to these or other equi-potential points and then balance the admittances from each. Referring to Fig. 7, if the testing current is applied at the points A and C, this condition is realized as shown by concentrating all ground capacitances at junction points B, C and D, and making the sum of the capacitances of junction points B and D equal to that of junction point C. This follows from the fact that when the bridge is balanced, the junctions B and D are equi-potential points. The mid-point of arm $C\,D$ is now at ground potential. If, however, the testing current is applied at the points B and D, the equi-potential points are the junctions A and C, the sum of whose ground admittances would then be made equal to that of D and the arm $C\,D$ again balanced with respect to ground potential. In this case there must be no ground admittance from junction B. To permit of testing under both conditions, point A and all connected conductors are protected with a shield which is then connected to point C. Point B is likewise enclosed by a shield connected to point D. These two main shields then represent the junction points C and D of the bridge and are fixed with respect to capacitance to ground by a ground shield which may be common to the two.

There now exist external to the local shields, direct capacitances only between points A and C and between B and D, (which do not affect the bridge balance), and from points C and D to ground. These latter do, of course, affect the balance. Two courses are open. Their effective resultant value shunting the arm $C\,D$ can be determined and allowed for by calculation. Such calculations would involve a considerable amount of labor, however, and can be avoided very simply by providing in the opposite arm an exactly equal shunt capacitance. To permit adjusting the ground capacitances of points C and D, an adjustable condenser is connected to ground from the point having the lower value. With the apparatus connected as shown this is usually point D. The shielded system then becomes as shown in Fig. 8.

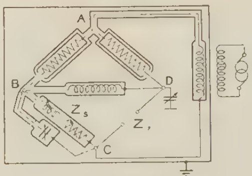

FIG. 8—SHIELDED BRIDGE CIRCUIT WITH BALANCING CONDENSERS

When impedances which, in actual service are grounded at one terminal, are to be tested, the matter is much simpler. Then it is necessary only to definitely ground one of the bridge terminals to which the impedance is connected and establish the proper initial capacitance balance of the bridge for this condition. This is readily done by grounding junction point C and adjusting the capacitance from B to C to equal the ground capacitance of D. The shielding system may remain the same as in Fig. 10.

In the case of the bridge being described it was desired to have a means of verifying by reversal the

3. U. S. Patent No. 792248, June 13, 1905.

degree of balance of the ratio arms and also that of the impedance arms. The bridge is therefore equipped with reversing switches for this purpose as shown in Fig. 9. In this arrangement all capacitances between the various parts of the switches which are subject to change due to physical movement of the switch parts are either short-circuited or connected across opposite bridge points and hence do not affect the bridge balance. The small capacitance C_R between the switch shield and that of the ratio coil R_2 shunts this coil and is not

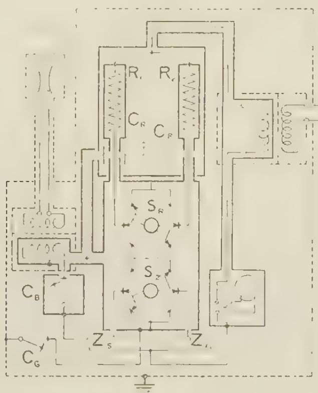

Fig. 9—Complete Circuit Diagram of Balance Unit with Shielding

carried with it on reversal. For this reason a corresponding capacitance C_R', shunting the coil R_1, is provided and connected to the opposite point of the switch. This is adjusted by test to equal the value of C_R. The diagram of Fig. 9 represents completely the circuit and shielding used for the balance unit of the bridge.

While, from the standpoint of the bridge balance alone, the parts comprising the standard impedance can be shielded with a local and ground shield as shown in Fig. 7, unless the standard has a very limited range, the resulting calibration is exceedingly laborious to make and use. To reduce calibration difficulties, additional shields can be used; this, of course, increasing the cost of construction. In arriving at the proper compromise between these conflicting factors the size and impedance value of the part to be shielded must be considered. This question will therefore be taken up in more detail in the following section.

Construction

As initially stated the bridge is intended for the measurement of audio and carrier frequency inductances. By this is meant all apparatus having reactance values nearly equal to the respective impedance values. For the purpose of the present discussion, such inductances will be more exactly defined as those having ratios of reactance to resistance of not less than 10 (minimum phase angle of 84 deg., 20 min.). The difference between the reactance and the impedance of any such inductance does not exceed ½ per cent. The impedance values range from about 100 to 10,000 ohms and testing frequencies from 500 to 50,000 cycles.

On the basis of these conditions, the following construction is used for this bridge.

Ratio Arms. It is desirable from the standpoint of sensitivity of balance to have the ratio arm impedances of approximately the same value as those of the other two arms. Considering the range of impedances to be covered and giving due weight to the values which are of most importance in telephone circuits, a ratio arm resistance of 1000 ohms was selected. The problem then was to construct two 1000-ohm resistances, balanced both as to effective resistance and effective inductance for a frequency range from 500 to 50,000 cycles when subjected to the usual temperature and humidity variations.

Curtis and Grover have discussed the factors affecting the characteristics of a-c. resistances and have suggested forms suitable for general use at frequencies up to 3000 cycles.[4]

In arriving at the requirements for the more extended frequency range of this bridge, the necessary phase-angle balance was first considered. Designating by L_x and R_x the inductance and effective resistance of the impedance being tested, and by L_s and R_s, the corresponding components of the standard impedance required to balance it in a bridge circuit having ratio arms of exactly equal resistances R but shunted by slightly different capacitances, C_1 and C_2, and assuming that the quantities are such that $\omega^2 R^2 C_1^2$ and

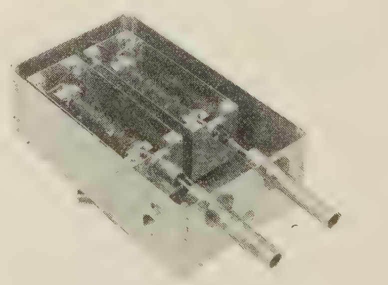

Fig. 10—Ratio Arms

$\omega^2 R^2 C_2^2$ are small in comparison with unity, the equation for balance is

$$(R_x + j\, w\, L_x)(R - j\, w\, C_1\, R^2) = (R_s + j\, w\, L_s)(R - j\, w\, C_2\, R^2)$$

which reduces to

$$R_x = R_s + w^2 R\,(C_2 L_s - C_1 L_x) \qquad (1)$$

and

$$L_x = L_s - R\,(C_2 R_s - C_1 R_x) \qquad (2)$$

Neglecting second order effects, these can be written

$$R_x = R_s + w^2 R\, L_x\,(C_2 - C_1) \qquad (3)$$

and

$$L_x = L_s - R\, R_x\,(C_2 - C_1) \qquad (4)$$

If the readings R_s and L_s are taken as the values of the unknown resistance and inductance, respectively, it is

4. H. L. Curtis and F. W. Grover: Resistance Coils for Alternating Current Work, *Bulletin of the Bureau of Standards*, Vol. 8, No. 3.

evident that errors as given by the last terms of these equations will be present. The percentage errors in the two cases are as follows:

$$\Delta R_x (\%) = 100\, \omega^2 R\, (C_2 - C_1) \frac{L_x}{R_x}$$

$$= 100\, \omega\, R\, (C_2 - C_1) \tan \theta \quad (5)$$

$$\Delta L_x (\%) = 100\, R\, (C_2 - C_1) \frac{R_x}{L_x} \quad (6)$$

For a given capacitance unbalance of the ratio arms, it is seen that the error in inductance is inversely proportional to the time constant $\left(\frac{L}{R}\right)$ of the impedance arm and is independent of the frequency, while the error in resistance is proportional to the frequency and to the ratio of reactance to resistance, that is, to the tangent of the phase angle. The inductance error is, therefore, maximum for the minimum time constant apparatus to be tested. Within the range previously mentioned this occurs when an impedance having the minimum reactance to resistance ratio of 10 is being measured at the minimum frequency of 500 cycles. Under this condition $\frac{R}{L}$ has a value of $\frac{2\pi \times 500}{10}$ or approximately 300. The corresponding percentage error in inductance per micro-microfarad of capacitance unbalance is then $300 \times 1000 \times 10^{-12} = 3 \times 10^{-7}$ or 0.00003 per cent. Evidently a very considerable unbalance can be tolerated. In the case of the resistance component, the error is maximum when an unknown impedance having the maximum reactance to resistance ratio is being tested at the maximum frequency. A reactance to resistance ratio of 300 is very rarely exceeded. For this value, the error per micro-microfarad unbalance at a frequency of 50,000 cycles amounts to about 9.5 per cent. Hence, to limit the error from this source to the order of 1 per cent requires a balance of about 0.1 micro-microfarad. It will be appreciated that this is an extremely close balance, the maintenance of which, under the different conditions of temperature and humidity to which the bridge may be subjected, requires careful consideration of the effects of these factors.

To meet their requirements, the bridge coils are constructed as follows. The spool used is a glass cylinder ¾ in. in diameter. The winding is applied as follows: Starting at one end of the spool, a single strand of the wire is wound on until 14 inductive turns have been applied giving a resistance of approximately 50 ohms. Then the wire is tied, the direction of winding reversed, and an exactly equal number of turns wound over the first 14, but in an opposite direction. This brings the wire to the point of the beginning. It is again tied, carried parallel to the axis of the spool over this first section and a second section wound. This is continued until ten sections have been applied. A thin sheet of mica is tied in place around the winding and the projecting ends of the wire bared of insulation. The whole is then baked to anneal the wire and dry the insulation. While hot, it is dipped several times in molten asphalt compound until a continuous coating of this moisture-proof material has been formed over the winding and surrounding mica wrapping. Adjustment for resistance balance is made by varying the length of the two wire ends.

The effective reactances of coils made as above are positive before assembly in their shields. The effect of the shield is to increase the capacitance. Table I gives data obtained on the two coils made for the bridge and shows the uniformity of phase-angle difference maintained by these coils over the operating frequency range. Final adjustment for reactance balance is made with the coils in the bridge circuit, a small amount of inductive coiling of the terminal leads sufficing for this purpose. In establishing this balance, use is made of the reversing switch described in the following section. Fig. 10 shows these coils assembled in their shields.

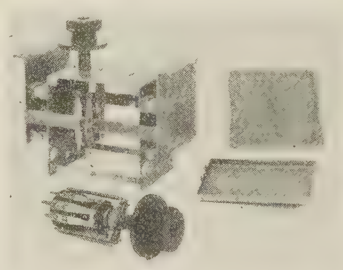

Fig. 11—Reversing Switches

TABLE I
EFFECTIVE INDUCTANCE OF RATIO ARM COILS

Test Frequency	Microhenrys					
	Before Coating		After Coating		Assembled in Shield	
	Coil A	Coil B	Coil A	Coil B	Coil A	Coil B
1000 cycles	7.4	6.9	6.7	6.3	−1.3	−1.0
50000 cycles	7.4	6.9	6.7	6.2	−1.2	−0.8

Resistance of each coil = 1051.2 ohms

Reversing Switches. As will be noted from the diagram showing the circuit arrangement of the reversing switches, these are required to be completely enclosed in a shield which is connected to the junction point D of the bridge. They must also, of course, be subject to manipulation.

The construction adopted for this purpose is shown in the illustration, Fig. 11, which is a partially assembled view of the two reversing switches, their shield and its supporting brackets. It will be noted that the shield is supported by the brackets by means of small glass rods (four of which are shown).

Transformers. The transformers used for isolating the bridge circuit electrostatically from the source of

testing current and from the detector system should have substantially zero external electromagnetic fields. This is to prevent inductive coupling to other parts of the bridge circuit. For this purpose the transformer core is made in toroidal or ring form and the windings, both primary and secondary, are uniformly distributed about its circumference. The wound toroid is also completely enclosed in a sheet iron case.

The winding which is connected to the bridge has an electrostatic shield completely surrounding it for the purpose of concentrating all capacitance currents at one point. Around this localizing shield there is a second or ground shield. These two shields are made of sheet copper approximately No. 30 gage (0.010 in.) in thickness. The inner winding terminal leads are brought out through a small brass tube leading into a terminal chamber which is an extension of the localizing shield. Since the admittance between the localizing and ground shields forms a major part of one of the balanced admittances shunting the impedance arms, it is desirable that the capacitance component be of low value and essential that it be constant. The conductance component should be negligibly small. To attain this end, the shields are separated at definite distances by means of hard rubber rings turned to fit the outer corners of the inner shield and the corresponding inner corners of the enclosing shield. These rings are made of the smallest cross-section consistent with mechanical strength requirements so as to introduce the minimum amount of solid material into the space between the shields. This minimizes the capacitance and conductance values. These shields must not, of course, be allowed to act as short-circuited secondaries on the transformer which would be the case if they linked conductively with the windings. Each is therefore made in two parts similar to toroidal channels which upon assembly have their overlapping inner circumferences insulated from each other by means of thin mica laminations. Further details of the construction will be evident from a study of Fig. 14.

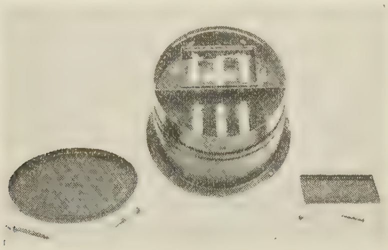

Fig. 12—Shielded Transformer

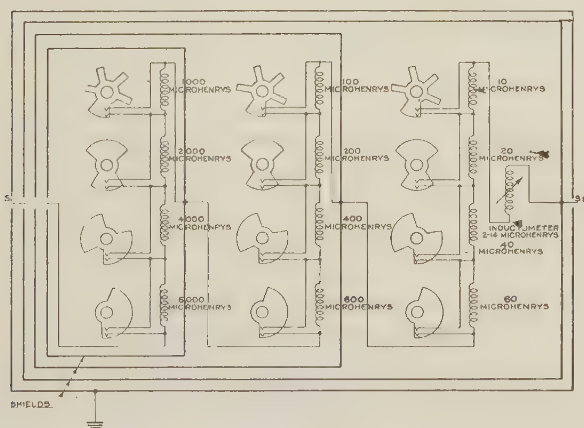

Fig. 13—Circuit Diagram of Shielded Inductance Standard

The windings are, proportioned so as to connect with a reasonable degree of efficiency the associated impedances. For best results two sets of transformers are used to cover the complete frequency range, one from 500 to 5000 cycles and the other from 5000 to 50,000 cycles.

Balancing Condensers and Impedance Arm Balance. It has been brought out previously that two adjustable capacitances are required, one C_G to effect the proper adjustment of the bridge capacitances to ground and the other C_B to balance the residual capacitances shunting one of the impedance arms. Such capacitances are provided in the form of adjustable air condensers each having a maximum value of about 500 micro-microfarads. The construction used is such as to give a high degree of stability of capacitance combined with low conductance characteristics.

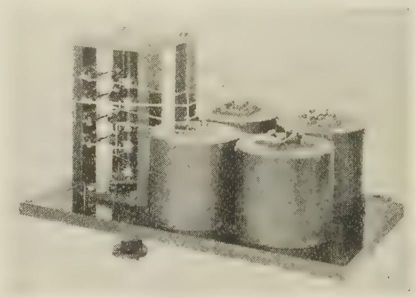

Fig. 14—Coil and Dial Switch Assembly of Typical Inductance Standard Decade

The effect on the accuracy of the bridge of the degree of balance of the impedance arms obtained by means of the balancing condenser C_B is determined as follows:

When the values of the shunting capacitances are small the errors for the purpose of indicating their order, are sufficiently closely given by the expressions,

$$\Delta L_x = \omega^2 L_x^2 (C_x - C_s) \tag{7}$$

and

$$\Delta R_x = 2\, \omega^2 L_x R_x (C_x - C_s) \tag{8}$$

where

C_x and C_s are the capacitances shunting the unknown and standard impedance arms, respectively. Reduced to percentages, these expressions become

$$\Delta L_x (\%) = 100\ \omega^2 L_x (C_x - C_s)$$

and

$$\Delta R_x (\%) = 200\ \omega^2 L_x (C_x - C_s)$$

and may also be written

$$\Delta L_x (\%) = 100 \frac{1}{C_R} (C_x - C_s) \qquad (9)$$

and

$$\Delta R_x (\%) = 200 \frac{1}{C_R} (C_x - C_s) \qquad (10)$$

where C_R is the value of capacitance that would be required for resonance with inductance L_x at the test frequency.

These errors are thus proportional to the ratio of the capacitance unbalance to the resonating capacitance of the inductance under test. Ordinarily, values of the latter factor do not go below about 500 micro-microfarads so that in the worst case a difference in capacitance of 0.1 micro-microfarad corresponds to errors of 0.02 per cent and 0.04 per cent in inductance and resistance respectively.

Shields and Wiring. The shields have sufficient rigidity and are supported so as to maintain a definite and constant space relation to the part shielded and to the other shields. They are also of sufficiently high conductivity to maintain a common definite electrical potential at all points with respect to the part shielded.

The supports of shields or of bridge elements within the shields are as nearly as possible of constant specific inductive capacity, have low dissipative and leakage losses and are restricted to the minimum in number and size consistent with meeting the required rigidity of support.

Interconnecting conductors are shielded within brass tubes of approximately ½-in. diameter, the conductor which is of No. 10 gage copper being supported at the axis of the tube by means of glass beads fitting snugly within the tubes and having holes through which the conductor passes. These beads are located longitudinally on the conductor by means of a small lump of solder placed on each side.

Standards. The impedance standards consist of adjustable self-inductance elements used in series with an adjustable non-inductive resistance. Each self-inductance element consists of a series of inductance coils and a low range inductometer of the Brooks type[5] arranged in three decade formation and connected to dial switches by means of which any series combination of the coils can be selected. The inductometer is always in circuit and permits of balancing inductance values that fall between consecutive steps on the dials. Fig. 13 shows, schematically, the connections used for these standards and also the way in which they are shielded.

5. H. B. Brooks and F. C. Weaver: A Variable Self and Mutual Inductor, *Scientific Paper of the Bureau of Standards*, No. 290.

The coils used in this bridge depart from the air core type ordinarily employed, in that they have a magnetic core of high stability and efficiency. Thus the desired inductance is obtained with a much smaller number of turns in the winding giving a satisfactorily low resistance even in a coil only a fraction of the size of the equivalent air core coil. An adaptation of the new magnetic material, permalloy, has made this type of inductance standard possible.[6] Their cores consist of finely laminated, high specific resistance permalloy punchings, carefully annealed and assembled to form a toroidal structure whose effective permeability is about forty. On this is wound a sectionalized winding of insulated stranded conductor, the individual strands also being insulated from each other. The wound coils, after adjustment to the value desired, are sealed with moisture-proof compounds in phenol fiber cases. Fig. 14 shows an assembly of the four coils and switch which comprise one decade of the standard. In Table II are given data for typical coils illustrating their performance in respect to the above points.

The adjustable non-inductive resistance is a commercial dial resistance box to which a shield has been added. It has five dials providing a range of 1000 ohms in steps of 0.01 ohm. Its shield is grounded in use, the resistance itself being connected usually between the *C* corner of the bridge and the inductance standard but in the case of an unknown impedance having a lower resistance than the standard from the *C* corner to the coil under test.

PERFORMANCE

As was explained in the foregoing two switches are provided for independently reversing the ratio arms (*A B* and *A D*) and also the outside connected impedances. These, therefore, afford a very convenient means of checking the balances of the bridge network. The following series of tests indicate how this was done on one of these bridges.

The junction point *C* was first grounded. Then, with a telephone receiver as the detector and with a test current having a frequency of 1600 cycles, the setting of the condenser C_b was varied until a balance was obtained. The arms Z_s and Z_x were both open-circuited in this test; hence the capacitances shunting these arms alone determined the balance point. This balance was very sharp indicating that the shunting conductances were either very small or else accidentally well balanced. Leaving the condenser set at its balance point, there was then connected into one of the impedance arms a toroidal self inductance standard having a nominal inductance of 0.200 henry and an effective resistance of about 50 ohms. In the other arm there was connected a similar standard of the same nominal but of slightly lower actual value in series with a small adjustable inductance and adjustable resistance, each of sufficient range to effect a balance

6. H. D. Arnold and G. W. Elmen, *Franklin Institute Journal*, 195, 1923.

TABLE II

DATA ON COILS FOR INDUCTANCE STANDARDS

	Frequency range	
	500 ~ — 5,000 ~	5,000 ~ — 50,000 ~
Overall Dimensions		
Diameter of case	6-1/2 in.	3-1/2 in.
Length of case	4 in.	3-1/8 in.
Inductance Characteristics		
Nominal value	0.100 henry	0.010 henry
Change with frequency	+ 0.5% (500 ~ — 5,000 ~)	+ 2.5% (5,000 ~ — 50,000 ~)
Change with current	+ 0.01% per milliampere	+ 0.007% per milliampere
Temperature coefficient	− 0.013% per deg. fahr.	− 0.005% per deg. fahr.
Residual magnetization effect of one ampere d. c.	Less than 0.01%	Less than 0.01%
Resistance Characteristics		
At an alternating current (effective value) of 2.0 milliamperes	1,000 ~ — 5.2 ohms 3,000 ~ — 8.5 " 5,000 ~ — 13.0 "	10,000 ~ — 3.6 ohms 30,000 ~ — 13.6 " 50,000 ~ — 34.0 "
10.0 milliamperes	1,000 ~ — 5.5 " 3,000 ~ — 9.1 " 5,000 ~ — 13.9 "	10,000 ~ — 3.7 " 30,000 ~ — 13.9 " 50,000 ~ — 34.7 "
Temperature coefficient	− 0.017% per deg. fahr. at 3,000 ~	− < 0.01% per deg. fahr. at 30,000 ~

of the corresponding constants. The extension inductance was graduated in steps of one microhenry and the resistance in steps of 0.001 ohm. Balances for the four-combination settings of the reversing switches, S_R and S_z, were then made, only the extension elements being varied in getting these balances. Readings as given in Table III were obtained.

TABLE III

Switch Position		Extension Inductance	Extension Resistance
S_R	S_Z		
Right	Right	124 ± 2 microhenrys	3.93 ± 0.01 ohms
Left	Right	120 " " "	3.93 " " "
Right	Left	124 " " "	3.93 " " "
Left	Left	126 " " "	3.93 " " "

As a further check on the performance of this unit, two inductances, each of about 0.01 henry inductance, were compared at two frequencies, 25,000 and 50,000 cycles. Table IV gives the readings obtained in these tests.

TABLE IV

Frequency cycles	Switch Position		Extension inductance	Extension resistance
	S_R	S_Z		
25,000	Right	Right	123 ± 1 microhenrys	5.1 ± 0.1 ohms
	Left	Right	122 " " "	" " " "
	Right	Left	129 " " "	" " " "
	Left	Left	128 " " "	" " " "
50,000	Right	Right	38 " " "	24.2 " " "
	Left	Right	36 " " "	24.2 " " "
	Right	Left	57 " " "	23.8 " " "
	Left	Left	57 " " "	23.8 " " "

Up to 50,000 cycles, the inductance change due to ratio arm reversal is within ± 0.01 per cent while the resistance change is within 0.1 ohm which would be just under one per cent for a coil of this reactance and a reactance to resistance ratio of 300. This is a critical test of the ratio arm phase-angle balance. Hence it may be concluded that over the entire frequency range the ratio coils meet all balance requirements. The changes in inductance occurring at the higher frequencies when the impedance arms were reversed indicated that the residual capacitance unbalance of these arms was too large. Readjustment of the balancing condenser reduced the changes to less than 0.02 per cent. The difference in resistance balance at the 50,000-cycle frequency indicates that the conductances shunting the impedance arms are not negligible at this frequency. For more accurate results these conductances would require balancing. This would be quite practicable by means of a variable high resistance shunt.

In making each series of tests outlined above, the testing potential applied to the bridge was varied by means of a resistance potentiometer from the lowest value at which a balance could be made to the maximum of the supply oscillator. This was to check the completeness of the shielding and to detect the presence of any coupling with the supply circuit. In no case was there any discernible change in balance produced.

Conclusion

A system of electrostatic shielding for a direct reading bridge for the measurement of inductive impedances at frequencies up to 50,000 cycles has been described.

The general considerations defining the balances of the various capacitances which this shielding controls have been discussed and specific requirements derived for a typical range of impedances. The physical construction of a bridge designed to meet these requirements has been described and test data given illustrating its performance. These have shown it to be capable of comparing impedances over the above frequency range with a precision which approximates that ordinarily found in routine direct current resistance measurements.

Suggested Transformer Voltage Standards

Their Relationship to Pacific Coast Practise

Committee Report[1]

H. H. MINOR, Chairman

Synopsis.—*Explanation of authorship and basis of paper. General discussion of the proposed system voltage standards and the principles underlying them. Listing of transformer voltages and kv-a. connected now in use by P. C. E. A. Companies. Detailed discussion of changes in proposed standards to bring them into conformity with Pacific Coast practise. Summary and conclusion.*

THIS paper is presented by the Subcommittee on Transformer Standardization of the Electrical Apparatus and Overhead Systems Committees of the Pacific Coast Electrical Association as the result of a study of transformer ratios made last year and a further investigation carried on during the past few months. It is felt that it will be of interest as part of a general discussion of the subject, system voltage standardization, as it is a composite of the views of representatives of the several Member Companies of the P. C. E. A.

The work last year was carried on by means of questionnaires and by discussion at joint meetings of the two parent committees. The table of "Proposed Voltage Ratings For Systems" presented to the National Electric Light Association by a special committee appointed by the National Apparatus Committee to study data collected by that body was discussed, in so far as it applied to transformers, at some length. This year a survey has been made of the voltage ratings and kv-a. capacity of transformers in use by P. C. E. A. Companies. Further discussion of possible new standards and the probable application of those suggested to Pacific Coast conditions was invited. The following is an attempt to present an analysis of the data collected and to present an outline of the opinions of the P. C. E. A. members that have come to the committee.

The general view is that there is need of revision of the present transformer standards with respect to voltage rating. The five principles upon which such revision should be based, as set forth in the Memorandum of the Special N. E. L. A. Committee which was published in the September 1926 issue of the N. E. L. A. *Bulletin*, are excellent.[2] Of these, principle *B* which reads: "The voltage selected must closely resemble those now in use to permit a reasonable degree of interchange ability of old and new apparatus" is of particular importance. It will probably result that this is the vital point to be considered in any attempt at revision of the standards.

Principle *C*, which states that the changes involved must not necessitate too great an expense in the development of new apparatus, is also of extreme importance. This expense, however, should be the expense to the user of the apparatus and not simply the cost of development and manufacture. It should include the probable cost to the user because of the fact that principle *B* is not adhered to, sufficiently. Most of the present-day systems for the transmission and distribution of electrical energy are so greatly involved through interconnection on their own systems and with other systems that the voltages in use are fixed within rather narrow limits. That present standard transformers do not lend themselves to use on many of these systems without operating them at considerable variance with their rated voltages and those upon which tests and guarantees are based, is very true. This has naturally resulted in the purchase of a great amount of "special" or "off-standard" equipment.

To be successful, a new set of transformer standards must result in a decrease in the percentage of such specially designed transformers purchased. This result must not be obtained, however, by the inclusion in the standards of a great number of new designs. Adherence to principle *B* will result in a great reduction in the special transformers but principle *C* will have to receive careful consideration so that the ultimate cost to the industry as a whole will be lessened. Thus the task before those to whom is delegated the fixing of standard voltages for systems is one of making such compromise as is necessary between an ideal or theoretical standard and the voltage ratings of equipment now in use in order to arrive at a result that will be most satisfactory. That this is no easy task is evidenced by the study made by the N. E. L. A. Special Committee.

The proposed set of standard voltages and the explanatory notes with them are a wonderful improvement in many ways over the present standards. It may be the best possible compromise to which reference is made above. Certainly very careful thought has

1. Pacific Coast Electrical Association Subcommittee on Transformer Standardization. H. H. Minor, San Joaquin Light and Power Corp., Chairman; K. B. Ayres, San Diego Consolidated Gas & Electric Co.; A. W. Copley, Westinghouse Electric & Mfg. Co.; J. H. Cunningham, General Electric Co.; H. S. Lane, Pacific Gas & Electric Co.; H. L. Sampson, Southern California Edison Co.

2. See also *Voltage Standardization of A-C. Systems from the Viewpoint of the Electrical Manufacturer*, by F. C. Hanker and H. R. Summerhayes, A. I. E. E. Winter Convention, February 1927.

To be presented at the Winter Convention of the A. I. E. E., New York, N. Y., Feb. 7-11, 1927.

been given to its preparation, that the weaknesses of the present system of voltages shall be largely eliminated. The transformers and their taps listed will fit nicely into the somewhat ideal simple system used as an illustration in the Memorandum of the Special N. E. L. A. Committee. That such transformers would fit as well into existing systems may be open to question. In the West, where transmission distances are long, the full load drops encountered in the lines are considerably greater than the limits set in this example. The result is that in many cases step-down transformers are purchased with a much greater range of taps than the proposal allows in order to arrive at flexibility in the use of these transformers over a large system, or variations in their voltage ratings are specified to conform with existing drop conditions.

The accompanying tabulation gives an idea of the great variety of voltages and ratios in use by the P. C. E. A. Companies. Also is listed in part the kv-a. connected of transformers of the different classes shown. While this is not a complete listing, due to lack of information from a few of the Companies, it is felt that it presents a fair picture of the transformer situation on the Pacific Coast with respect to the possibility of arriving at a new set of standards that will fit into existing conditions.

A study of this tabulation shows that in the lower voltage classes, which include the great number of distribution transformers supplying utilization voltages, approximate conformity with the proposed standard exists. There are some changes, however, that seem advisable in view of present practise. In the higher voltage classes there is not such close conformity to the proposed ratings. The very great variety of voltages used is due in part to the above practise of specifying special transformers for use at different points on systems. For the most part, also, the larger systems have been built up by a gathering together of many small systems and interconnecting them by means of transmission lines. Each of these smaller companies had their own particular voltages and they were usually continued by the use of more or less "special transformers." This also has contributed to the great variety of transformer ratings.

The use of 2300-volt, delta-connected systems of distribution, supplying 110 to 115 volts to the consumer, has been the original set-up of most systems. As load density increased it became necessary to provide greater capacity to existing lines. The logical set-up and the one taken by most of the Companies was to use 2300 volts connected Y or the so-called 4000-volt system. In many cases the lines were made three-phase, four-wire, the 2300-volt class transformers being connected Y-delta for three-phase service and from phase wire to neutral for single-phase service. As the territory covered grew and longer feeders became necessary, it was found best economy to discontinue stringing the neutral wire and make use of a special 4000- to 115/230-volt transformer for single-phase use on these lines, still employing three 2300-volt trans-

TABLE OF TRANSFORMER VOLTAGES IN USE AND KV-A. IN TRANSFORMERS CONNECTED TO LINES OF PART OF P. C. E. A. COMPANIES

Nearest voltage class	Primary voltages (Full winding)	Secondary voltages (Full winding)	Kv-a. connected
2,400	2000 to 2900 volts	110 to 850 volts	1,055,200
	(2300 predominant)	(115-230 predominant)	
4,150	3810 to 4800 volts	110 to 2300 volts	23,721
	(4000 predominant)	(115-230 predominant)	
6,900	6000 to 7900 volts	110 to 2300 volts	469,753
	(6900 predominant)	(115-230 predominant)	
11,500	10,000 to 12,500 volts	110 to 2300 volts	625,210
	(11,500 predominant)	(115-230 predominant)	
13,800	13,200 to 14,400 volts	110 to 850 volts	9,400
	15,000 to 18,000 volts	110 to 2400/4150 Y	421,000
23,000	20,000 to 26,400 volts	110 to 6900 volts	46,706
	20,000/34,600 Y and	2200 and 2300 volts	10,087
	22,000/39,000 Y.		
34,500	29,705 to 36,415 volts	110 to 4150 volts	257,266
		6900/11,950 Y	91,075
		7500/13,000 Y	44,500
	(Connected Y on	11,500 volts	13,500
	66-kv. systems)	13,200 volts	72,110
		17,000 volts	3,000
		22,000 volts	18,667
34,500	33,000 volts	2400-11,500 volts	20,000
	(Connected delta)		
34,500	38,100 to 41,600 volts	110 to 4150 volts	139,092
		6900/11,950 Y	39,825
		7200/12,500 Y	200,000
	(Connected Y on	7500/1300 Y	8,350
	66-kv. systems)	11,500 volts	187,000
		16,500-11,500 volts	323,000
		22,000 volts	8,250
		2400-11,500 and	580,000
		16,500-33,000 volts	
69,000	50,000 to 76,200 volts	110 to 4150 volts	72,388
		6900/11,950 Y	138,333
		7200/12,500 Y	12,000
	(Connected Y on	7500/1300 Y	112,833
	110-kv. systems)	11,500 volts	181,817
		13,200 volts	164,167
		17,000 to 17,500 volts	9,900
		31,215/54,000 Y	26,667
		34,640/60,000 Y	135,500
		45,800/79,300 Y	185,000
69,000	50,000 to 66,000 volts	110 to 4150 volts	37,800
		6900/11,950 Y.	10,750
		11,500-16,500 volts	121,000
		20,000/34,600 Y	5,000
	(Delta connected)	22,000-11,000 volts	9,000
		36,000 volts	900
		2400-11,500 and	95,000
		16,500-33,000	
88,000	81,000 to 88,000 volts	2000 to 2400 volts	28,250
		11,500-2400 volts	167,500
	(Delta connected)	36,000-6600 volts	76,700
		55,00-2300 volts	37,500
110,000	110,000 volts	9500/16,450 Y	37,500
	(Delta connected)		
132,000	115,470 to 127,000 volts	11,500 volts	206,739
	(Connected Y on	63,500 volts	166,667
	220-kv. systems)	66,000 volts	369,000
		72,000 volts	315,000
154,000	150,000 volts	66,000-16,500 volts	305,000
	154,000-115,000 volts	11,000	80,000

formers connected Y-delta for three-phase service. This practise has been and is being extended rapidly. One manufacturer has catalogued a 4000-volt distribution transformer. It would seem advisable to include such a transformer in the proposed standards. Its rating, to conform with the Y voltage of the 2300-volt transformer, should be 3980 to 115/230, etc., for step-down transformers.

The next higher voltage class of transformers in use is the 6900-volt. As shown by the accompanying tabulation, there are a great many of this class in use on the Pacific Coast. There are, however, very few 6900-volt delta systems or lines. The almost universal practise is to use these transformers connected Y-delta on 11,500-volt systems, just as the 2300-volt class is used on 4000-volt systems. The present standards recognize this use by making the rating for distribution transformers of this class 6900/11950 Y to 115/230, etc.

There are also in use many 11,500-volt class transformers on these same systems, either connected delta-delta for three-phase service or used separately for single-phase loads. There is, however, a discrepancy between the ratios of these transformers and the 6900-volt class in the present standards. The relationship between these two classes should be as 1.73 is to 1 instead of as 1.67 is to 1, which is present practise. The practical result has been that the 6900-volt class is connected on the 6585-volt tap and the 11,500-volt class on full winding to more nearly approach the proper secondary voltage when both classes are connected to the same line. This, in effect, cuts down the available taps on the 6900-volt transformer and the user is paying for more than he needs.

In the proposed standards the actual ratios of these two classes are changed. The step-down proposal is respectively for the 11,500-volt system and the 6900-volt system, 11,000 to 115/230, etc., and 6600 to 115/230, etc. The relationship between them is still as before: 1.67 to 1. No provision is made in the proposed standard, however, for Y-operation of the 6900-volt class transformer. To conform as nearly as possible with the proposed standards and also with the Pacific Coast practise, it will be advisable to make the proposed standard for these two classes substantially as below:

System	Step-up Primary	Transformer Secondary	Step-down Primary	Transformer Secondary
6,900	6,600	6,900	6,600/11,430 Y	6,900
11,950	11,430	11,950	11,430	11,950

This rating of the step-down, 6900-volt class transformer will require it to be tested for 11,950 volts under the recommendation of the Special N. E. L. A. Committee that high potential tests be based on "rated circuit voltage" of the system of which the apparatus forms a part. That this is correct for such transformers connected Y is undoubtedly true. Should there be sufficient use of 6900-volt transformers on 6900-volt circuits to warrant it, it may be advisable to include both the above suggestion and the 6900-volt step-down transformer for use on 6900-volt delta lines. This is not the case on the Pacific Coast as practically all of the 469,783 kv-a. listed in the accompanying table are used on 11,500-volt systems.

In the proposal of the N. E. L. A. Special Committee, the following recommendation is made in "Note F" accompanying the proposed Table of Voltages:

> "When possible, 11,500-volt systems should be discouraged in favor of 13,800-volt ones."

On the Pacific Coast this suggestion is not at all possible. The practise, mentioned above, of using both 6900- and 11,500-volt class transformers so universally on 11,500-volt systems cannot be changed without immense cost. To change to 13,800 volts would necessitate the replacement of more than 1,000,000 kv-a. in 6900- and 11,500-volt distribution transformers and almost as much capacity in station transformers serving them. It is the unanimous opinion of the P. C. E. A. membership that the 11,500-volt system should be retained with such changes as are necessary to bring it into conformity with the 6900-volt class step-down transformers, connected Y on such systems.

The failure to include a 6900-volt class of transformer for Y operation in the proposed table is really only a special case of a general condition. The very great use of Y-connected transformer banks for both step-up and step-down purposes seems to point to the advisability of including such transformers in a new set of standards. That this use of transformers is large on the Pacific Coast is shown by the accompanying table. Of transformers above the 13,800-volt class there were reported approximately 4,000,000 kv-a. connected Y and about 1,000,000 kv-a. connected delta. The proposal of the N. E. L. A. Committee only includes transformer voltages for use connected delta, with the single exception of the 2300/3980 Y for step-down and 2400/4150 Y for step-up high voltage ratings. That inclusion of transformers for Y-connection for the various system voltages chosen will approximately double the number of transformers in the standards, is evident, but it will not greatly increase the number of designs necessary and should not increase the cost of either class. If the proposed standards were to be adopted, those companies using Y-connected transformers would be forced to buy "special equipment" and the designs, patterns, etc., would still have to be made.

The "General Note" accompanying the Table of Proposed Voltage Ratings referring to guarantees of efficiency, heating, overload, etc., and over-voltage tests has caused some comment. It is felt that this note is correct with respect to over-voltage tests of primaries of step-down transformers being based on five per cent over rated primary voltage. This is necessary to care for the over-excitation of the transformer

necessary to overcome transformer regulation drop. The same provision, however, would seem advisable for the primary or low voltage winding of step-up transformers. With these it is also necessary to over-excite approximately five per cent in order to supply rated secondary voltage at full load, due to transformer regulation. It would seem that this same result would be obtained, however, if the suggestion, mentioned before, that all apparatus have high potential tests based on "rated circuit voltage" of the system of which the apparatus forms a part, were adopted.

"Special Note E" states that transformers should be designed to operate during emergencies at five per cent above rated voltage, the over-voltage being obtained by over-excitation. Comment has been made that this statement is very indefinite. The question is asked as to just what constitutes such an emergency and how long such an emergency might be allowed to exist. In the Memorandum of the Special N. E. L. A. Committee the loss of one or more of a parallel group of transmission lines, causing abnormal drops between sources of generation and utilization, is cited as an emergency. One can well imagine such a condition lasting for many hours or even days when the lines are in mountainous and inaccessible regions. Under such "emergency" operation the transformer would be subject to the same conditions as would obtain for continuous operation in this over-excited condition. Another emergency that is often encountered on almost all systems is the sudden failure of apparatus or lines that will cause a large block of load to be disconnected from a long transmission system. The result is a very decided rise in voltage at points distant from the source of energy due to the decrease of line drop and transformer regulation.

Referring to the Memorandum of the Special N. E. L. A. Committee and particularly to Fig. 2A therein, let it be assumed that this represents part of a system at full load served from a 13,800-volt and 2400-volt distribution system. In order to approximate probable practical conditions let it also be assumed that there are four such 69-kv. radical feeders from the 132-kv. line, each carrying 25 per cent of its load. If, then, a fault should occur which would open up the 13,800 feeder switches and drop their load, the five per cent regulation drop of the 66,000- to 13,000-volt transformers would be eliminated as would the 4.5-kv. drop in the 69-kv. line and 25 per cent of the line drop and transformer regulation of the 132-kv. line and the 126,000- to 69,000-volt transformation respectively. This would result in approximately 18 per cent over-excitation of the 66,000- to 13,200-volt transformer. Thus this emergency, which would of course be of very short duration, would cause very much over the five per cent set up by "Note E." It is suggested that a more exact statement of the meaning of "emergencies" should be included in these notes.

As stated above, the long transmission distances in the West make it advisable to allow quite large line drops at full load, and this condition has made some of the companies specify quite a range of taps for their step-down transformers. The following is from one of the larger P. C. E. A. companies:

"While it may be possible in the eastern part of the country with concentrated loads in relatively restricted areas to keep transmission line drops within the limits indicated by the discussion of the proposed standards and consequently to maintain the transmission system voltage level with only four 2½ per cent taps in step-down transformers, we do not consider this economically practicable under the conditions prevalent on this coast. Our system, for instance, is spread over a veritable empire, with widely scattered power sources and load centers, and we find it necessary to provide taps for about 17½ per cent, particularly for transformers connected to the transmission systems. For instance, our present practise for transformers connected to our so-called 60-kv. system provides for two 5 per cent taps and one 7½ per cent tap, enabling these transformers to be used interchangeably on any part of the system. We therefore feel that more than 10 per cent in taps should be provided by these standards, either in 2½ per cent or larger steps as may be found necessary." Other companies operating over extensive territories find the same conditions confronting them and the practise of employing a greater than 10 per cent range in taps is quite common. Thus the "Special Note E (b)" might also be given more thought.

To summarize the foregoing briefly, Pacific Coast practise in the use of transformers points to the advisability of some change from the present standards. The proposed standards are a great improvement over the old and the principles upon which they are based are sound. There is need of the inclusion of a 3980-volt step-down distribution transformer and of a change in the 6900-volt and 11,500-volt class to bring them into conformity for operation on the same 11,500-volt lines. There is a distinct need of the standards including transformers rated for Y-connection as well as delta connections on standard systems. The "General Note" referring to over-voltage tests could be clarified as could the "Special Note E" referring to emergency operation. More study of the advisable range of taps on step-down transformers seems advisable. "Special Note F" suggesting the elimination of 11,500-volt systems is not at all in keeping with Pacific Coast practise.

In conclusion, it might be repeated that the task before those responsible for the formation of a set of voltage standards is a most difficult one. It must be a compromise between the ideal and the practical. Its result must be an economic gain to the industry as a whole.

Fifty Years Progress in Electrical Communications[1]

BY M. I. PUPIN

(*Continued from page 61, January Journal*)

A Missionary Effort which Succeeded

I trust that I will be pardoned for speaking now about my own missionary efforts among the unbelievers in the telegraph and telephone industries. I began to make these efforts a few years after Hertz, by his classical experiments, had clarified my ideas and everybody else's ideas concerning Maxwell's meaning. At that time I had never even heard of Heaviside or of Vaschy and of their advocacy of high inductance, but I had heard from my friends in the telephone industry of the inefficiency of telephonic transmission and of the failures to improve it by increased inductance. It was obvious that the increase which they described was too small and full of absorptive losses. Highly efficient coils of large inductance inserted at periodically recurring intervals into the line was the remedy which I proposed. But I was told that the remedy had been tried and that a dismal failure had resulted. I was also reminded that universal experience recommended the removal of inductance coils from telegraph and telephone lines; their interference with transmission, they said, had earned for them the opprobrious name "choke coils." It was clear that I had to furnish a proof which would convince even the most prejudiced among the telephone and telegraph engineers that inductance coils in a transmission line do not always act as "choke coils." Such a proof would have been worthless if it had consisted of mathematical formulas only. I needed the formulas myself for my own guidance, but watching the developments in wireless telegraphy which was born at that time I learned that full-sized apparatus and successful operation was the only proof which would appeal to the so-called practical engineer. He is like the man from Missouri who "wants to be shown," by actual experimental performance and by nothing less. My mathematical solution of the problem of transmission over a lumpy telephone line containing inductance coils at periodically recurring points filled me with confidence; it had never been even attempted by the advocates of high inductance. They evidently had missed an important concept in the physical character of the transmission problem. The length of the wave to be transmitted was not considered and hardly ever mentioned by them, and hence their failure to recognize in it one of the fundamental elements in the study of transmission of magnetic action over such a line. Instructed by the Hertzian experiments in which the wave length occupies a place of honor, and guided by Maxwell's general theory, there was no difficulty in recognizing the simple physical truth, plainly exhibited by my mathematical analysis, that the periodically recurring intervals between the inductance coils had to be considerably less than half a wave length of the transmitted wave, if they are to produce a beneficial effect. Under these conditions the transmission line acts like a uniform line of high inductance. All experience suggested that this simple rule, when pointed out, is obviously true; even the telephone engineers twenty-five years ago could understand it, and they liked it. At my suggestion they made the coils in their own way, using no iron core, inserted them into their own transmission line without my meddling and found by experiments, conducted by themselves, that my simple rule was correct, although they had made a clumsy error in the construction of their coils. They were converted by their own experience in the practise of the new doctrine, and I began to consider myself a successful apostle of Maxwell's gospel. But the telephone engineers wanted more. They wanted an inductance coil which does not disturb the transmission in neighboring lines; I consulted Faraday and Maxwell and gave them a symmetrically wound toroidal coil and they welcomed it, because they found to their great surprise that no outsider listening in the immediate vicinity of the coil can tell anything about the motion of electricity through the windings of such a coil. There was no appreciable cross-talk between adjacent coils belonging to different transmission circuits. Then the engineers amplified their requirements and demanded a coil of small dimensions, so as to be able to put a large number of them in a single pot. I consulted Maxwell again and gave them a suitably laminated toroidal steel core; they welcomed it. Finally they wanted a core of fairly constant permeability; I consulted Ewing's and Lord Rayleigh's magnetic researches and gave them core laminae of cold rolled steel; they welcomed that, too, after I had supplied them with an experimental method of testing my figures relating to the efficiency of these coils. Then they surprised me with a strange request; they asked me to go to court and prove that I had not been anticipated by anybody. In other words, I was called upon to carry on a missionary propaganda among lawyers and explain to them Maxwell's doctrine, in order to prepare them for a demonstration of the validity of my claim that I had done something which the other missionaries, who preceded me, had not done. I

1. Conclusion of the Presidential Address delivered December 27, 1926, by Professor M. I. Pupin, retiring president of American Association for the Advancement of Science.

succeeded speedily, thanks to the psychological fact that the unprejudiced mind of a lawyer is much more easily converted than the mind which is hemmed in by the narrow experience of some technical practitioners. This imprisoned mind can not be liberated except by the irresistible force of experimental demonstration. Heaviside and Vaschy trusted too much to mathematical symbols; they offered nothing which is tangible and of immediate value to the practical engineer. Hence the failure of their missionary work among the unbelievers in the art of Electrical Communications.

Wireless Telegraphy and Maxwell's Doctrine

The early history of wireless telegraphy illustrates the wisdom of the procedure which I have just described. I witnessed the birth of wireless telegraphy and watched its growth from the very beginning; that taught me how Maxwell's gospel must be preached among the unbelievers. A few brief statements relating to this interesting bit of history will explain my meaning.

A youth of barely twenty was repeating in the laboratories of the University of Bologna the Hertzian wave experiments; they were still fresh in everybody's mind and many an ambitious young physicist was doing the same thing in other university laboratories which young Marconi was doing at Bologna. But he was the only one who thought of trying a Hertzian oscillator consisting of a long and grounded upright wire and a similar Hertzian detector. The Hertzian pulse, excited in the oscillator in the usual way, was felt in the detector at quite a long distance, much longer than Hertz or anybody else had ever reached. Maxwell's theory, reinforced by higher mathematics, could have easily explained this remarkable increase of the distance. But young Marconi knew very little about these things and had no time to consult Maxwell's theory or even Heaviside's or Vaschy's interpretation of it. He packed his crude apparatus, took it to London, and called on the very unbelievers whom Heaviside could not budge. He put his apparatus into their hands, they operated it and found that it could do what no other telegraphic apparatus could do; it could send signals to ships at sea and receive an answer from them. Communication with the ships at sea! Just imagine what that meant to the British mind! Nobody understood that better than young Marconi. This understanding marked him as one of the greatest practical psychologists that the world had ever seen. One who is a follower of the belief that there is nothing new under the sun might say, and some have done so, that Marconi's invention was no invention at all, because it was an obvious inference from the Hertzian wave experiments. The courts have thrashed that out to Marconi's and everybody else's satisfaction; they found that he is the real inventor, and that he is the best type of inventor: experimental achievement first, and theoretical elaboration afterward. It was Marconi's experimental achievement which converted the British high priest of unbelievers who enjoyed all the official privileges of his mighty throne in the British Post Office, and whom Heaviside could not convert. Just think of it! A Heaviside equipped with the biggest guns of higher mathematics and guided by the greatest general, Maxwell, failing in his attacks where an Italian youth with nothing but crude wave apparatus and blazing southern imagination and enthusiasm succeeded! The high priest of the British Post Office surrendered and the mighty British Navy followed suit; the unbelievers had finally caught the first glimpse of Maxwell's meaning and they bowed their heads in deep reverence. This was the most picturesque victory recorded in the history of science. Marconi's maneuvering which ended in this victory taught me how to preach the doctrine of high inductance to the telegraph and telephone engineers. Not mere words, pictures, and formulas but experimental demonstration.

It should be observed, however, that telephone engineers showed a much greater inclination to listen to Maxwell's gospel after our city fathers, some thirty years ago, had passed a law which ordered that within city limits telephone wires must be put under ground. This was a great service to the apostles of the high inductance doctrine. The city fathers who rendered this service were perfectly unconscious of their great aid to science as well as to the art of electrical communications. Underground wires, so-called telephone cables, could not transmit articulate speech over much more than a score of miles without a great increase of their inductance, and that demanded a great increase in scientific knowledge in telephone engineering. How well the telephone engineers have responded to this demand may be gathered from resolutions adopted recently in Paris at an international conference of telephone engineers. They resolved that in international telephonic communications over great distances it is both practicable and advisable to operate with telephone cables equipped with inductance coils in accordance with principles first demonstrated in my laboratory as practicable over twenty-five years ago. "Cables pupinizé" is the international name for such cables. This is a graceful compliment on the part of the European telephone engineers; our telephone engineers lack the artistic temperament which seeks expression in graceful compliments.

When my missionary work among the telegraph and telephone engineers started in the nineties they had already caught a glimpse of Maxwell's teaching, thanks to the irresistible appeals of the Hertzian experiments reinforced by Marconi's wireless transmission. Self-induction was "in the air" according to a statement made by Sir William Thomson, when he first heard of the Hertzian experiments, and immediately Heaviside made the following caustic comment upon this epigrammatic remark:

"Then there are the electromagnetic waves. Not so

long ago they were nowhere; now they are everywhere, even in the Post Office . . . Now these waves are also in the air, and it is the 'great bug' self induction that keeps them going."

I wonder what Heaviside said about their "going" when twenty-five years ago they leaped across the Atlantic carrying a message from England to Newfoundland! Heaviside said thirty-eight years ago that the British engineers' self-induction was standing still and would not move. It would be fairly good guessing to-day to credit Heaviside with the opinion, suggested by Marconi's England-Newfoundland leap, that the self-induction of an Italian youth in his early twenties was "going" so fast that its momentum was greater than that of the self-induction of all British telegraph and telephone engineers put together.

Long distance telephony and telegraphy over wires of high inductance and the bridging of the Atlantic by Marconi's waves were, twenty-five years ago, the most striking experimental interpretation of Maxwell's meaning in terms of a language which was intelligible to the engineer. This language and the story it told was inspired by the appearance of the Hertzian waves. The art of electrical transmission of messages over wires or without wires became thus a part of the great science which Maxwell had formulated. This, added to Bell's great invention, the invention of the telephone, will be recorded as the greatest asset with which this art entered into the twentieth century epoch of its history.

The Twentieth Century Progress

No development in the technical arts illustrates so well the intimate connection between abstract science and its applications as the rapid development of wireless transmission during the last twenty-five years. Marconi's sharp electrical pulses, resembling cracks of a whip, were soon replaced by fairly sustained oscillations obtained by the obvious instrumentality of coupling to Marconi's oscillators suitable inductance and capacity. This prepared a place for patiently waiting electrical tuning and selectivity in Marconi's scheme. It was badly needed, and I had it developed several years before Marconi had made his invention but many other things were badly needed before this electrical selectivity could prove its full value. These additional things, like, for instance, the high-frequency dynamo electric generator, were gradually supplied. Wireless transmission stations began to look like offsprings of good engineering design. But the conviction grew strong that without a fundamentally novel element in the wireless transmission scheme further progress would be slow. That additional element was found in a modest corner of the science of physics. There sat, unnoticed by the practical engineer, the tiny electron and waited patiently to be harnessed in useful service to the art of electrical communications.

The Roentgen rays were discovered at about the same time when Marconi exhibited his wireless scheme to the British Post Office. Nobody expected that Roentgen's vacuum tube phenomena had anything in common with wireless transmission. The study of these phenomena revealed the existence of the electron, the infinitely small electrical unit whose independent existence had been prophesied by Maxwell long ago. It was this infinitely small servant which rendered incomparably great service to electrical transmission, both with and without wires. Wireless telegraphy was so revolutionized by this service that a new name was invented for it. It is called "Radio" to-day. Similar revolutionary changes were introduced by this service into the other types of electrical communications. The service of this infinitely small servant is remarkable not only on account of its magnitude but also on account of the ideal simplicity of its performance. A word or two regarding it will be helpful.

The study of the Roentgen's phenomena led to the discovery that a hot electrode in a vacuum tube throws off electrons. Such an electrode in a vacuum tube will keep it filled with electrons. They are there as a swarm of many billions of tiny electrical units moving within the tube's vacuum in a perfectly non-coordinated fashion. They are an electrical mob, each member of this mob moving in its own sweet way. Introduce now into the tube a cold electrode and connect it to the hot electrode by an electrical battery, the hot electrode being connected to the negative and the cold electrode to the positive pole of the battery. The electromotive force of the battery immediately transforms the electrical chaos in the tube into a beautiful cosmos of coordinated motion. The vast and chaotic army of tiny electrons, like drilled soldiers obeying the command of the battery voltage, march in orderly columns from the negative to the positive electrode. One end of the columns disappears as it enters the positive electrode and the other end of the columns receives new electronic recruits from the hot electrode. This beautifully coordinated motion of the myriads of tiny electronic units is the steady electrical current sustained by the battery. It is known today as the thermionic current. Few of us are aware that it was discovered forty-two years ago by an humble German high school professor. Investigating in a modest school laboratory the motion of electricity in rarefied gases, he discovered that even a small electromotive force obtained from a Voltaic cell can sustain an electrical current between a hot carbon electrode and a cold electrode in the highest vacuum obtainable at that time, provided, of course, that the hot carbon electrode was connected to the negative pole of the cell. The discoverer was W. Hittorf; he showed that this current produced no luminosity in the very highly rarefied gas of the tube; it was therefore a thermionic current of today. Hittorf's historical experiment, though seldom mentioned, and Roentgen's experiments leading to the discovery of the electron are the second source of science from which the art of electrical communications drew during the last twenty-five years the

nourishment for its vigorous growth. A few words, only, relating to this nourishment.

Not only was the thermionic current a familiar phenomenon forty-two years ago, but moreover, other characteristics of this current were also known. I mean the interaction between the cathode current and external electric and magnetic fields. Over twenty-five years ago it was known that the motion of electrons in a vacuum tube is deflected by electric and by magnetic forces and this interaction was often employed by J. J. Thomson and by others in the experimental determination of the ratio of the charge of an electron to its mass. From this knowledge there was one step only to the introduction of a third electrode for the purpose of modifying the flow of Hittorf's thermionic current. Thomson had actually introduced several electrodes for the purpose of modifying the direction of flow of the cathode stream, so that the introduction of the third electrode for the purpose of modifying the intensity of Hittorf's current may be said to have been obvious; but often it takes a long time to do the obvious thing. It was actually done by several inventors in the beginning of this century. This gave us the vacuum tube amplifier, the vacuum tube oscillator, and the vacuum tube telephonic repeater. They gave that extraordinary vigor to the art of electrical communications during the last twenty-five years, but they are the product of that nourishment which was prepared in the fertile soil first cultivated in the modest laboratories of two humble German professors, Hittorf and Roentgen. This nourishment should be labeled "Made in Germany." Listen now to the pathetic statement which the discoverer of the hot cathode vacuum tube, Hittorf, made forty-two years ago:

"Gladly would I have devoted a more searching study to these interesting and unexpected phenomena, in order to establish their quantitative relations. But the powerful currents which the chromic acid battery supplies are too unsteady. It is impossible to maintain the constancy for a sufficiently long time of the white heat temperature of the carbon (electrode) which is needed for measurements.. A dynamo-electric machine would in this respect be better. Unfortunately the modest means at my disposal for these experimental researches do not permit me to buy one."

The little dynamo-electric machine would have cost about twenty-five dollars!

The amplifier and the oscillator have created radio broadcasting, including radio telephony between England and the United States. The vacuum tube telephonic repeater cooperating with high inductance telephone cables has united New York, Chicago, and St. Louis into one telephonic community. Before many years have passed all big centers in the United States will be united into one telephonic community. The European telephone engineers at the international conference, already referred to, have adopted this American method of long distance telephony for the purpose of uniting all great European centers into one telephone community. One can easily imagine what this means to international understanding and the peace of the world.

When we speak of electrical communications we usually mean exchange of messages between human beings. But a careful study of the static, of the fading of radio communications, and of the so-called earth currents in cables will undoubtedly reveal that they are not, as usually believed, disturbances only which annoy the clumsy methods of human operators. They are in all probability messages transmitted to us by cosmic activities and are far more important to mankind than mere communications between mortals. The sun, for instance, is a white hot body in the interstellar vacuum and the electronic emission from the hot electrode of our thermionic tubes makes it obvious that there must be a most gigantic electronic emission from the sun. Hale discovered that the cyclonic motions in a sunspot are accompanied by a powerful magnetic field, that is by most powerful electrical currents. Other phenomena may be cited to show that the sun is the seat of an intense electrical activity. One can not resist the temptation of imagining that this activity is closely connected with static, fading, and earth currents in submarine cables. Perhaps these perpetual sources of annoyance to the electrical transmission engineer and operator are a blessing in disguise. The fading and the earth currents in submarine cables may be manifestations of very long electrical waves sweeping through our planetary system and carrying with them the story of slowly varying electrical activities in the sun. The art of electrical communications is in a splendid condition today to attack cosmic phenomena of this kind and furnish accurate knowledge where today there is only guessing and speculation. I hope that one of the great advances of this art during the next twenty-five years will be found in the solutions of these cosmic problems by deciphering the messages which static, fading, and earth currents are communicating to us.

A novel use for electric lighting is being employed in the cotton raising country of the southwest as a means of ridding the fields of the ravages of the cotton moth. It is understood that a cotton raiser near Tornillo, Texas, is using electric lights for this purpose on his farm. Lamps have been strung along each row of the plants and at night the light attracts countless insects which come in contact with the lamps and fall in the cans containing kerosene conveniently placed beneath each light. Thus the moths are exterminated before having a chance to lay the eggs from which are hatched the worms which are so disastrous to the cotton crop. A similar method has been used in the eastern states as a protection against the ravages of insects which feed on the foliage of peach trees.—*Trans.* I. E. S.

Discussion at Pacific Coast Convention

ENGINEERING EDUCATION: ITS HISTORY AND PROSPECTS[1]

(HENLINE)

SALT LAKE CITY, UTAH, SEPTEMBER 7, 1926

F. E. Terman: The future of engineering education may be profoundly affected by the work which the psychologists are beginning on special interest and special aptitude tests.

The Psychology Department of Stanford has devised an interest test to separate men practising the legal, medical, and engineering professions. This test contains no technical matter, and yet it distinguishes between engineers, doctors and lawyers with about 90 per cent success. That is, if one gives the test to a hundred lawyers, a hundred doctors and a hundred engineers, the interest test will correctly name the professions of about two hundred seventy of the three hundred tested.

The Stanford Psychology Department has devised also a test of scientific aptitude. This test was given to about a dozen graduate students studying electrical engineering and the men were ranked in order of their scientific ability as shown by the test. This ranking was then compared with an independent ranking made by the electrical engineering staff. The two rankings were identical with the exception of one or two students out of the dozen or so ranked.

Thus the one-and-a-half-hour test alone was able to tell about as much regarding the scientific ability of these students as could be discovered in from one to two years' contact by several teachers.

These two tests are illustrative of a movement that the psychologists are just starting, and which appears to have great promise, particularly in vocational guidance and engineering education.

J. H. Johnson: I "enjoyed" one of these courses about fifteen years ago and desire to give my impressions from a study of the suggested course.

The course I pursued was quite similar to the one outlined, except that it was slightly heavier—in that it averaged about eighteen hours where sixteen hours is now suggested. I strongly favor the heavier work.

Rather early in Mr. Henline's paper, he suggests a liberal policy as to electives. I fear the results of such a procedure and believe it much better to offer a "cast-iron" schedule. The student does not like a rigid schedule and in theory I agree with him but practically it appears to be necessary. The average student does not know what he wants. He does not know what courses will best prepare him for his future needs. Conflicts as to time further complicate the problem—to the end that unless a course of study is carefully prepared, the electives end in courses such as typing, glee club, orchestra, or wrestling. For these reasons I object to the rather large amount (about 12 per cent) of electives outlined.

Since courses as given in some colleges are so presented that essential ideas are scattered scantily through a large mass of unimportant elaboration, it appears to me that when it is deemed advisable to give engineering students courses such as economics, business management, and so on, the work should be condensed and reduced to its more important component principles in the same fashion as in his engineering texts. To secure this treatment, it may be necessary to have the work given in the College of Engineering.

Further, as a general thing, I would remind you of the old objection to a five- or six-year engineering course, *i. e.*, the fact that it graduates a student at a correspondingly later and to the employer, less desirable, age.

G. S. Smith: The field of engineering education is being subjected to a great deal of careful scientific research, and already these studies have resulted in the formation of some very definite ideas. So far, it has not been possible to give many of these ideas a fair trial because the general public, upon whom the state universities at least are largely dependent, will seldom sanction a change, especially if it means added expense, until they are educated to realize its value.

However, it is very gratifying that the engineering profession in general is taking such a keen interest in the methods to be used in our engineering colleges. Fortunately, the larger companies are doing more and more to help the engineering colleges to a higher standard. Would it be too much to ask that these larger companies, and in fact the whole engineering profession, help educate the general public to realize these needs? The advances made in engineering education will no doubt prove valuable to education in general.

It is becoming more and more evident that the best engineering professor is not only well versed in the fundamentals of engineering which he must teach, but must also specialize in some branch of that work to the extent that he may be considered authoritative in his specialty. Such a professor will prove an asset to the institution he serves and an inspiration to the students with whom he comes into contact. Here again the larger companies are cooperating in helping faculty members to a higher standing in their profession and offering them opportunities of contact with the practical field. Here also the institution might well offer some incentive for the professor to build up his reputation, and avail himself of the opportunities offered.

The success of many of the ideas which have been put into practise is apparent from Professor Henline's paper. He mentions the courses in general engineering problems now required of engineering freshmen in some colleges. This work has met with fine success at the University of Washington. It gives the student a fair idea of that to which he may look forward and either gives him a good start in his chosen field, or causes him to realize he has been mistaken in his choice.

Those faculty members who have charge of the junior and senior courses might well study and lend their influence toward directing students into the field of work for which they are best fitted. For example, it is often apparent to the professor whether a student is adapted to such fields as research, design, shop or mechanical details, executive work, etc. A little personal advice and aid might stimulate a student to aims which otherwise he may never develop.

That marked advantage is to be gained by having certain required non-engineering courses taught by engineers has been supported by some and questioned by others. While this is seldom possible except in the larger schools, it seems very desirable for the more fundamental subjects, such as engineering mathematics, and at least one course in English. Another alternative that has met with some success is to segregate the engineering classes in such subjects and select some instructor from the faculty of that department to specialize in teaching these classes from the engineering point of view.

R. W. Sorensen: I think it absolutely impractical to make a standard engineering curriculum. I can see no reason why all schools should be alike. Individuals and communities differ from each other, and regardless of our efforts to direct young men along the paths we think they should follow, they seem to do work largely according to their natural abilities. At California Institute of Technology we aim to guide students in the selection of courses and assist them in making efficient use of their time; but we also endeavor so far as possible to give the student the widest latitude as to the manner in which he shall do his work. For several years the classes have been divided into groups according to scholastic standing, the various groups doing work we think best suited to their special abilities. The

1. A. I. E. E. JOURNAL, September, 1926, p. 801.

results of this plan have been wholly good. The Institute faculty has never been satisfied with a one-year course in English for engineering students. When our course was a four-year course, the students had a four-year course in English and associated humanities. The time given to this work was approximately one-fifth of the total time spent on college work. I can report also that our engineering students have not considered these subjects uninteresting or things to be avoided if possible. For example, we have several times had requests from students for additional classes in English and last year we had a request even more surprising than one for additional English—a course in the study of Greek. This was probably due to the fact that Dr. Macarthur, one of our English professors, had so inspired the men with some discussion of Greek Literature as to incite them to a desire to study from the original, methods of Greek thought. Under such conditions I am certain that the course in Greek as given by Dr. Macarthur was a very valuable one. We have always endeavored to make English just English, —not engineering English,—believing that most engineers not only do not write reports well, but cannot expect to learn to write reports well if they endeavor to learn only to write reports rather than learn to make the fundamentals of English and English literature an integral part of the means used by them in expressing ideas.

D. I. Cone: Men of the industry who are not on college faculties have a very great interest in the matter of engineering curricula. If there were no other reason for it the young men being trained would very soon be taking up the work of assisting us in our problems; so we do well to encourage the school to give the best possible training. Just to consider the great variety of topics upon the program of this Convention is to become convinced that a broadly developed curriculum is necessary to fit the student to be appreciative of it. We should, therefore, extend our heartiest interest and our congratulations to the Stanford faculty for undertaking this forward step.

The problem of the fifth and sixth years of training raises a challenge to us of strengthening means for assistance to those students who find difficulty in going on; that is, men who would need to devote a large part of their time to earning their own way. A further problem calling for continued study by the men of the industries and colleges is that of cooperation in bridging the gap between the college life and the ensuing life in industry. It seems clear, however, that the solution of this is not to be found in a specialized curriculum.

H. T. Plumb: Many young men come to me for help in choosing engineering and college courses, and I generally give them four rules as a safe guide for starting out on a college career.

First: During high school and the first three years of college, at least, "study fundamentals."

Second: Avoid early specialization.

Third: Study in school what cannot be learned outside of school.

Fourth: Become an all-around man and do not specialize in any one subject until you have a general knowledge of all. Elect studies that will develop your low spots.

About these four rules I have thought for many years and believe them to be generally good. I think that too much of instruction and not enough of education is attempted in engineering. Education should develop or lead out. All courses should seek first to develop the man and then to add a little knowledge of engineering for him.

The larger engineering firms are coming to demand college men and are willing to teach them the engineering afterward. They are willing to teach their particular form or method of engineering. I think we should not train to be engineers only. That is not the prime object. We have to live and we should educate ourselves and train ourselves so that we can help with the greatest amount of judgment and with the greatest amount of service to our fellow beings.

We are three-sided by nature, and if we neglect the training of any one of these sides, then we reduce the efficiency of the whole.

D. C. Prince: It seems to me that many people have entirely too low an opinion of the college undergraduate. They seem to think that they have to outline everything he should do. It would be interesting if someone would take all the material of the four-year college course and take a good active boy and turn him loose on it. I think he could clean up four years' work in two years.

K. B. Miller: I think we have to admit that the educators are up against a very hard problem and that they are trying to solve it. The most promising thing is that they are trying to solve it in a scientific way. Looking back over my experience as a graduate from one of the technical universities, I have beee forced to the conclusion that the average engineering graduatn was a pretty lopsided individual, mostly because he had tried to specialize too soon. I do not object to a man having a definite idea of his future, but I think he should be guided and given a chance before he commences some course for which he will not be well adapted. His judgment is not as good as it will be later on and I think I take issue with Mr. Prince on that particular question; not as regards all men, but as regards the rank and file. Most of them do not know what they want to do at the time they enter college. Give a man a pretty good education and do not allow him to specialize too soon. A man will be so much better able to tackle his line of work if he does not specialize too soon in any one thing.

Harold Michener: It seems very important to me that young men should have some choice of instructors. Do not make the curriculum so rigid that those who are bright enough to do so cannot choose the best instructors giving the desired or required courses. Do not, by putting the cultural subjects under instructors in the engineering departments, deprive the engineering students of the opportunity of studying these subjects in outstanding courses under outstanding instructors, such as, in my time, Prof. Gayley's course "Great Books."

L. N. Robinson: It is gratifying to read in Professor Henline's paper that another positive step is being taken toward the better and broader education of engineers.

One can hardly criticise the curriculum proposed without intimate knowledge of the individual courses. It appears to me, however, that it would be preferable to spread English composition and public speaking over at least the first three years, devoting one unit each of the autumn and winter terms to grammar, rhetoric and themes, and one unit of each of the spring terms to the presentation of prepared speeches, the reading of technical papers written by the student, and extemporaneous speaking.

The course, "Human Relations in Business," appears interesting and I wish Professor Henline would tell us more of the content of this course. Human relations in business can hardly be taught comprehensively without giving a course on human relations in general; and in view of the state of modern society, it appears that it might be desirable to include the subject of domestic relations. It is to be presumed that the course will be offered with a scientific treatment to conform to the methods employed in teaching the theories of physical phenomena, and I wonder what text is to be used?

For a long time it has seemed to me that sooner or later some of the engineering colleges will visualize the importance of teaching the fundamental principles of human relations. Professor Henline alludes to the necessity for this when he ranks the "understanding of men" (often called "ability to handle men") high among the requisites of an engineer, especially if he would attain an executive position. Incidentally, to handle men should not mean manhandling, as too many old-school executives and others believe; it should mean to guide them,—subordinates, superiors and contemporaries. How can that ability be developed?

Now-a-days, we depend almost altogether on the students and graduates learning by merely casual contact and hearsay,—often accompanied by bitter experiences,—what they can and cannot profitably do. Would it not be far more rational to teach them the fundamental principles and give them such laboratory work along these lines while in college as would better prepare them when they graduate, just as we endeavor to equip them with the fundamental laws that govern physical phenomena? Where shall we find these fundamental laws governing human relations?

There is no place where they are so well codified and demonstrated as in the New Testament of the Bible. You may object to my proposing to introduce religion into our colleges. Are we not already putting too much blind faith in our scientific knowledge and adhering too religiously to theoretical fetishes? How many of our so-called scientific laws have stood uncontroverted anywhere nearly as long as the scientifically founded laws of human conduct voiced by Jesus Christ and his disciples? How many have stood half, or even one-tenth, as long?

I hold no brief here for any creed or sect; in fact I would be one of the first to object to introducing into any school a course in blind religion as such. The genuine Christian doctrines, however, as differentiated from sectarian dogmas, are not founded on blind faith. They are rational and demonstrable, permitting of the same scientific methods of analysis and experimentation as the commonest laws of physical phenomena. When they are studied openmindedly by scientific methods and confirmed by experiments and observation, the student will feel fully justified in clinging to them just as religiously as he now clings to Newton's laws and Maxwell's equations despite an Einstein.

Professor Henline's paper advocates a six-year course for engineers. This appears to be predicated on the assumption that 15 units per term is about the permissible maximum. Should we not examine such an assumption very carefully before we cut two years out of every engineer's life? Practically, it amounts to killing him two years before the end of what would otherwise be his useful career. Nevertheless, this assumption is commonly accepted in most colleges, although it seems a reckless waste of students' time and highly conducive to their immorality.

If I am not mistaken, 15 units correspond to 15 hours of classwork and 30 hours of homework per week, with suitable adjustments for drawing and laboratory periods, so that the student is expected to fulfill the requirements of the course by applying 45 hours per week.

After he graduates, the student will be expected to work at least 45, if not 54 or more, hours a week. Furthermore, he will be expected to spend four or five evenings of, say, three hours each, in study and self-betterment, or a minimum of 57 and a maximum of not less than 69 hours. Why train him in laziness at college? On the other hand, any ambitious high-school graduate who is forced by circumstances to go to work, would be expected to work at least 45 hours and probably more per week, attend night school two or three evenings per week and study the intervening evenings. Why should earnest college students do less with their manifold advantages? Is it any wonder our students need automobiles, supper dances and gin to fill up their idle time?

In conclusion, I believe the best of engineering curricula can be condensed very practicably and advantageously to not more than four years of nine months each, giving between 20 and 25 units per term and requiring an average of approximately 60 hours of application per week.

F. O. McMillan: It appears that most persons associated with or interested in engineering education are quite generally convinced that four years is a short time in which to train for an engineering career. These people in general, are also convinced that the fundamental principles of science and engineering and the humanities are of prime importance. Yet with these points conceded, we are still confronted with the problem of training many engineering students who enter the colleges and universities with a desire and a determination to be trained in some specific branch of engineering, such as electrical, mechanical, civil, etc. These students, many times excellent scholars, are unable for financial or other reasons to continue their education longer than four years. How are we to hold the interest of such students in a four-year general engineering course?

Obviously, one way to hold interest in the general engineering course would be for the industries and others employing these engineering graduates to announce publicly that, other conditions being equal, the four-year graduate having a general engineering education will be given preference over the four-year graduate specializing in the branch of engineering for which they are seeking employes. Are the employers of engineering graduates, outside of a few large corporations having well established training systems, willing to do this? If so the problem is already a long way toward being solved.

Another phase of Professor Henline's paper is that which has to do with the vocational-guidance value of a four-year general engineering course in assisting students to choose their major branch of engineering for the two-year post-graduate course. My personal observation has been that students undecided upon their major course are very largely influenced by the relative personality, enthusuasm and ability of the professors in the various major departments between which the student must choose. This obviously, many times, is detrimental to the best interest of the student because it fails to take into consideration special aptitude and many other points that are vital. For this reason it occurs to me great care would have to be exercised in the presentation of engineering subjects during the four-year general engineering course to avoid the aspect of selling one branch of engineering in competition with another.

G. R. Henninger: One thing, that at first perhaps, reacts negatively upon all of us is the idea of extending courses of engineering study to include more than four years. However, it is of importance to remember that the prime objective of an education is nothing more nor less than to bring the present generation up to date. It is obviously necessary that the individual learn what has gone on before in order to progress logically and economically.

Engineering has branched out in many ways. That of itself makes it essential that more of the engineering student's time be devoted to study. Further in support of the proposed longer courses is the accepted fact that the graduate engineer must have more cultural and commercial training if he is to step into active practise without a serious setback.

The soundest foundation that a young fellow can get, regardless of the nature of the work that he may take up in later life, is a course in engineering fundamentals. Thus at least on two counts I have great regard for the proposed "four-plus-two-year" course developed by Professor Henline, at least as a starter in the right direction. The practising engineer must assist in this.

Regarding the "cast-iron schedule:" Most of my thoughts have already been spoken by others, but I should like to add my urge against too rigid a schedule. It would seem that our educators themselves are in a most advantageous position to give to the individual student something in the way of individual guidance.

Another word of warning should be voiced against the tendency to bring under the control of the engineering department those courses of cultural value that are so badly needed by the student engineer. If liberalizing subjects are brought within the influence of the engineering department they lose at once at least 50 per cent of their broadening value. Perhaps the one outstanding exception to this is mathematics. Theoretical mathematics and the mathematical proficiency that will be most useful to the majority of engineering graduates differ widely. In this one case, therefore, it would be of advantage for the engineering

department to have under its influence the study of engineering mathematics.

David Hall: I have come in contact with many students in the Engineering School of the Westinghouse Electric & Mfg. Co. and I have observed that students well grounded in fundamentals easily take the lead. We have a course first on d-c. machinery, then on induction motors, a-c. generators, transformers, control, etc. After the first two or three sessions, one can pick out the leaders among those students. In about two sessions you can pick out the ones best adapted to engineering. The leaders are picked out because they have good fundamental grounding in the studies. They understand the underlying principles. When they get the underlying principles, they can take the subjects and handle them in a masterly manner.

There is one point in this paper where the author says that "70 per cent of the men of those in classes out fifteen years or more are in work primarily administrative, etc." Now, because 70 per cent of these men are in administrative work the author concludes that they should have been trained for administrative work. My conclusion is that the technical education has already trained them for administrative work and the proof lies in the fact that they are selected by their superiors for administrative work.

J. P. Jackson: Engineering education in this country has been developed under the supervision of strong men of brilliant mind. Evidence that a sound foundation has been builded is to be found in the great, beneficent influence wielded by our college-trained engineers in the upbuilding of American industry.

In making changes, therefore, it should be with a view to building further on the existing base being extremely careful not to cut away any but occasional rotten spots.

With the author, I am convinced that as development proceeds we shall put into our engineering courses more of the humanities. An engineer should be the most useful and influential man in his community. To be so he needs a practical knowledge of government, social customs, of business methods, and of how to handle men. The strengthening of his training along these lines while in college will result in some cutting on the scientific side of his training; but this should be done carefully or a stunted growth will result.

The author states rightly that generally character has been considered a most important element in making a good engineer. When I was Dean of Engineering at Penn State the members of our enginering faculty unanimously decided to give a certain definite proportion of their time to the study of how best to instill the various elements, such as honesty, industry, tolerance, thoroughness, justice, humanity, etc., into the embryo engineers within their care, and also to devote a definite portion of their class time for this purpose. The results as I observed them were eminently helpful, and I believe not only tended to emphasize the importance of sound ethics in the minds of our engineering students, but to increase their enthusiasm and inspiration for their scientific and technical studies. The older professors were generally able to draw their material for this kind of teaching from their own experiences in the engineering field, while the younger ones were expected to confine themselves mor especifically to the biographies of great engineers and industrialists.

With regard to the course schedule on the sixth page of the author's paper, permit me to say that I cannot agree comfortably with the use of the B. A. degree for application to a course so substantially scientific as the one he gives. For such a long span of years, courses leading to B. A. degrees have been those which prepare for careers dealing with the fine arts, literature and kindred subjects or professions, that it seems to me to be a distortion of good, sound English language to apply it to such a course as the one given. I should like to know from the author and from the great university which offers the course, what is wrong with the degree, Bachelor of Science?

I believe no one would have serious reason to criticise the fundamentals of the general course on the sixth page. To my mind, it would be far wiser to put the work on citizenship in the fourth instead of the first year. If taught as I conceive it should be to a college man, it is one of the most important subjects of the student's course and requires the brain training of a senior student. I should also use the term "industrial history" instead of "history," not for the purpose of cutting out a suitable review of the political phases of history, but for the distinct purpose of emphasizing the enormous effects of industrial and scientific development on civilization, particularly during the past one hundred years.

I should like to add one more word about this course. If the great institution which is using it continues to offer also the regular engineering undergraduate courses, without question or doubt, there will be a small handful of students enrolled in the general course and a small army will continue to go into the ordinary engineering courses. In the regular engineering courses and of great value there is created a certain amount of professional spirit which attracts students and which is not usually so evident in a general course. My own past practise and present belief is that much the same result as desired by the author can be obtained by suitably broadening the existing engineering courses to the point where differentiation is of a comparably slight amount, though I am not at all disposed to the addition of such a general course as he has outlined.

H. H. Henline: I agree fully with Dr. Terman that the interest and scientific aptitude tests which have been developed promise much for the future. We have had the experience of rating in numerical order, two classes of graduate students in electrical engineering using as a basis their scientific aptitude as exhibited in class and laboratory, and comparing our ratings with those made by a graduate student in psychology who had given these classes a special scientific aptitude test developed as part of his own graduate work. Both times our ratings agreed very closely with his. The need for some such means of determining that for which each student is best fitted is very great, and such tests should be given a fair trial.

The fact that the curriculum under discussion contains only about 15 units of work per quarter instead of 18 has been mentioned by Professor Johnson. I can assure him that the majority of the students will find all the work they can do well. He said a "cast-iron" schedule with no electives is better. I cannot agree with this at all. How can we tie men down to a very rigid schedule for four years and hope to find them showing any originality after leaving school? It is better to allow them a little freedom of thought, and give them a chance to strengthen their weak spots. An objection has been raised to this in that many men may choose easy courses. This possibility is, of course, present, but the best that can be done is to give students whatever guidance may be necessary and encourage them to develop their own individualities in the proper directions.

The plan of having English, economics, mathematics, and other such courses for engineering students given in the engineering schools exclusively has been the subject of many arguments. With ideal instructors, perhaps these and other subjects should be given by engineering teachers, but men who know both engineering and the other subjects sufficiently thoroughly and are willing to do such work are rare. The students should by all means have contact with those who are teaching such subjects on account of love for the work, and should not be restricted to teachers who are giving those subjects merely because they are useful tools for engineers. They need the broadening effect as much as the subject matter.

Issue has been taken with the Stanford plan on the apparent assumption that the four-year curriculum will not prepare students thoroughly. We believe they can go out at the completion of it, prepared to enter many types of engineering work and well prepared for the commercial phases of engineering.

The six-year idea has been criticized because it would hold students in school two years longer than the great majority now stay. As just stated, we believe that the four year curriculum furnishes good preparation for entering actively into the engineering field and those who can follow that with two years of graduate study will have an excellent preparation for their life-work. The first function of a university is to supply the foundation for good citizenship. The second is to train for definite fields of usefulness. The second is important, but it should not be allowed to replace the first.

The question has been raised as to whether we are placing too much emphasis upon training for administrative work and too little on technical education. Records given in the paper indicate clearly that a broad education is of greater importance than training in technical subjects. The plan is to lay the foundation for all life and to build upon it a moderate amount of engineering education. A few courses such as economics, geology, psychology, etc., will awaken students to interests extremely important in later development, with which they might not come into contact for several years if such courses were omitted.

Mr. Robinson has asked for more information on the nature of the course, "Human Relations in Business." This is to be developed and given by the Department of Psychology primarily to meet the needs of engineering students for some training in those fundamental principles governing human relations which one must know if he is to deal successfully with people. It will be given by means of lectures, and adapted to the requirements of the students as well as practicable.

The desire of young men to specialize in some branch of engineering immediately after entering the university is often mentioned as an argument against the more general curriculum. The S. P. E. E. investigation has developed the facts that the great majority of young men entering the engineering schools have chosen particular branches of engineering, and that more than half of those who have made such choice have done so with little or no real information regarding the branches chosen or their fitness for them. It seems necessary to teach many young men that technical subjects are not the only ones needed in an engineering curriculum.

Mr. Jackson has asked what is wrong with the Bachelor of Science degree. Stanford has always given the Bachelor of Arts degree in all departments with the idea that no distinction should be shown between those who graduate in literary subjects and those who graduate in the more specialized subjects, such as engineering. The degree given in all cases is Bachelor of Arts in.......................

Citizenship is given during the first year, rather than during the fourth as Mr. Jackson suggested, on account of the desire to place it where it will be most helpful from the standpoint of orientation and the development in the student's minds of a sense of their responsibility as citizens.

PROTECTION OF OIL TANKS AGAINST LIGHTNING[1]

(Peek)

Salt Lake City, Utah, September 8, 1926

Joseph Slepian: There is one point that has bothered me about which Mr. Peek may be able to reassure me. The model experiments, show quite definitely the existence of a protected area around a lightning rod, but I do not feel so certain of the quantitative applicability of the results to practical cases. If the electrostatic field only is considered, model tests give quantitatively correct results. If, with a set of electrodes, the scale of dimensions is reduced in any ratio we may be sure that the electrostatic field will be faithfully reproduced on the smaller scale. But not so with discharges; there we have another factor coming in. Discharges or sparkovers depend upon the distances between molecules of the gas. It would seem that if the experiment with discharges is to be made on a small scale the distances between molecules of the gas should also be reduced so that absolutely correct model experiments should require molecular distances to be reduced in the same ratio or the pressure of gas to be increased in the same ratio. There is a theorem bearing on this, relating to similarity of discharges given in Townsend's book on "Conduction of Gases." It is that if the dimensions of electrodes are reduced in a given ratio and the gas pressure is increased in the same ratio at the same time, the sparking potential is unchanged. It may be that these model experiments are correct but there is this little doubt. This doubt will be removed if it proves true that the ratio of protected radius to rod height is independent of the scale on which these experiments are made. Very likely Mr. Peek can set that point at rest if he has made tests on different scales and has still obtained the same ratio of protected radius to rod height.

R. W. Sorensen: During the summer of 1926 a number of engineers in Southern California have been trying to find out how to protect oil reservoirs from lightning fires. There were a few strikes of lightning in Southern California early in the year. These few strikes did millions of dollars worth of damage, because some of them set fire to oil stored in reservoirs. Up to the time of the fires of last spring, the oil companies were confident that oil stored in reservoirs represented a small risk for damage which might be caused by lightning. The peculiar coincidence which made three bad oil fires due to lightning occur within a period of about three weeks immediately produced great excitement, which resulted in the opinion that the frequency of lightning storms in Southern California was rapidly increasing. Impelled by this excitement, engineers undertook investigations and laboratory tests to determine the probable danger due to lightning and means for guarding against such danger. Some conclusions have been reached. One is that there are fewer electric storms along the Pacific Coast than in any other place in the United States. Another is, oil in storage presents no special inducement for lightning to strike the tanks containing oil, or in the immediate vicinity of such tanks. Beyond this I feel that as yet we know very little about complete lightning protection.

Mr. Peek, with his equipment and knowledge of high-voltage phenomena, is obviously the one who has the most knowledge concerning laboratory experiments with apparatus constructed to produce in the laboratory electric discharges simulating as nearly as possible those due to lightning. From these tests Mr. Peek has drawn the conclusion that lightning cannot hit within an area circumscribed by a circle having a radius of four rod heights drawn about the rod as a center.

I am in no position to question Mr. Peek's law as to what lightning will do, but I have a record of several thousand shots made from a point to a plane, the shots being recorded on sheets of paper in the manner used by Mr. Peek. These shots were made with direct current obtained from kenetrons without the use of condensers with condensers charged by direct current from kenetrons, with 50-cycle alternating current directly from a transformer and with discharges from a surge generator as used by Mr. Peek. Our surge generator of course had different constants from those of the surge generator used by Mr. Peek. The data to which I refer include tests made with spark-gaps ranging from less than 2 in. to 14 in. in length. Using these gaps connected to the circuits mentioned, we find a very appreciable percentage of the electrical discharge striking the plane surrounding the metal rod within a distance of less than four rods height from the rod. Mr. Peek has suggested that we get strikes within this distance because our gap lengths are short. I see no reason why gaps 5 or 10 in. long should act differently from 30-in. gaps, as used by Mr. Peek. In making these laboratory tests we used rod heights varying from ¼in. to 1 in. The rod height in every case was designated as 150 ft. Using the rod height as the unit, the spark-gap distance for each test was set to represent

1. A. I. E. E. Journal, December, 1926, p. 1246.

a cloud height one might expect to find during thunderstorms. The minimum height in each test represented 1000 ft., while the greater number of thunder clouds probably have an average height of 3000 ft. I have data for more than 900 shots made with varying rod heights, and for each rod height for varying gap lengths. From this data I should conclude that for the spark discharges we used there is approximately 43 per cent protection, rather than complete protection, for the area within the four-rods-height circle. Mr. Peek has suggested that our results differ from his because we have circuits which oscillate. Perhaps that is so, but I doubt if we are in possession of sufficient information to declare that no oscillations will ever occur in actual lightning strikes. At any rate, the results we obtained for spark discharges from a point to a plane upon which is mounted a projecting metal rod in our work at Pasadena are not the same as those obtained under the conditions used by Mr. Peek in Pittsfield, Mass.

With regard to the protection of tanks having rods erected around them, we have found that three points around a small metallic tank in the laboratory afforded practically no protection against sparks from a point directly above the center of the circle inclosed by the three rods, most of the discharges going to the space between rods. With sparks up to 14 in. in length the results were approximately the same for all spark lengths. Four rods and six rods around a model tank furnish a considerable degree of protection for the space surrounded by the rods, but give by no means complete immunity.

We have also done some laboratory work to determine the area protected by wires but our time does not permit discussion of the results obtained in these tests. I will therefore close by stating that I do not wish to appear to question Mr. Peek's experimental results in any way, but I do believe that at the present time we are not justified in concluding that Mr. Peek's laboratory tests as reported give complete data as to how an area can be given complete protection by rods spaced according to his four heights rule.

B. F. Howard: I should like to ask Mr. Peek if it is possible—economically possible—to prevent potentials which would cause lightning to build up on clouds in the neighborhood of oil tanks or of wire lines. During this year I have carried out an experiment at Colorado Springs in order to try and prevent two areas of cables being damaged by lightning which heretofore have been so damaged every year. We have had very severe lightning at Colorado Springs this summer and so far we have received no damage due to this cause on these protected cable areas, whereas serious damage by lightning to other cables which were situated around and close to these areas has been experienced. The damage did not appear to be the result of direct strokes but more of induced charges on the wires disruptively discharging to the sheaths on their way to ground at the time of a nearby lightning flash.

The method of protection followed was this: The two cable areas in question are each about half a mile long and the construction which was done several years ago was on the old system of ground wires being placed at every tenth pole. These connected with the cable sheaths and messengers and to ground. The soil is good for making a satisfactory "ground." This is rather unusual, for in Colorado Springs there are often pockets of earth which are not well electrically connected with the main ground. A galvanized wire was run up each pole and connected to the messengers and cables and to an ordinary ground rod driven in at a little distance from the base of the poles. No sharp bends were allowed and the tops of the wires were carried to a height of 6 in. above the poles and each was sharpened to a needle point. The poles for three or four spans on each boundary of the cable areas were included. The idea was that each pole within the areas and several poles around them would act as leakers and so prevent or reduce potentials building up in the nearby clouds sufficiently to prevent lightning discharges from them.

It is a rather bold attempt to try to control lightning, but "the proof of the pudding is in the eating." The fact remains that while cables in other parts nearby have been seriously damaged, and I believe the power people experienced a good deal of disturbance from lightning this summer, the cables in these areas so far have remained undamaged. Of course I may be mistaken, as the effects of lightning are so uncertain and we may find next year that we have had some damage done to these cables, notwithstanding the protective conditions.

M. E. Dice (by letter): Mr. Peek lays down some very definite rules representing the results obtained by using models subjected to "voltage from the lightning generator as well as all other types of voltages." He says the same general results were obtained from all types of clouds,—points, spheres, and planes. The one thing he has not done to make the record complete and the rules applicable is to compare these results with the records of actual lightning strokes. It would be very convincing if he could show historical data from insurance companies and from the many published observations on lightning which would substantiate the laboratory results.

F. W. Peek, Jr: I quite agree with Dr. Slepian's criticism. So long as the problem is purely an electrostatic one, an exact solution can be obtained from a model. The induced voltages on the ground wire, the effect of a net, etc., are purely electrostatic problems. In the study of direct strokes, electrostatic conditions are represented by the model up to the point when the spark occurs. There is reason to believe from a study of lightning strokes that the model also represents actual conditions after the spark occurs. Of course it is not possible to reduce the size of the atoms to correspond to the scale. Tests were made, however, over a wide range of scales with substantially the same results. In other words, for a given arrangement and ratio of rod and cloud height the results were independent of the scale.

Since I have not seen Prof. Sorensen's data, I cannot discuss it in detail nor venture an opinion as to the exact cause of the apparent discrepancies. There are several ways in which it can be explained. For the short sparks used in his tests, high-frequency oscillations are quite likely to occur. Such oscillations change conditions and do not represent the effects caused by an impulsive or highly damped discharge of a lightning stroke or longer spark. On several occasions we have had similar trouble for various reasons but have always been able to determine the cause and eliminate it. Reference to my Fig. 19 will show that the protective ratio varies with the cloud height-rod height ratio. I do not know whether or not Prof. Sorensen made allowance for this.

Since this paper was written, I have extended the tests to include d-c. voltages up to 350 kv. When the cloud is negative, the results are very much the same as in Fig. 19; in fact, the protective value is somewhat better. When the cloud is positive, a curve similar to Fig. 19 is obtained. The protective ratio, however, is less for a given cloud-rod ratio than it is for the negative cloud. For instance, in Fig. 19 a protective ratio of four is given for a cloud-rod ratio of ten. When the cloud is positive the protective ratio of four may not obtain until the cloud-rod ratio is about twenty. Theory and some measurements indicate that the cloud causing the discharge should generally be negative. Also, the lightning voltage just previous to the discharge is generally not steady direct current.

The values given in Fig. 19 are ratios where the rods just do give protection. In using these figures it is, of course, desirable to allow a certain factor of safety.

I doubt if appreciable protection can be obtained by corona discharges as suggested by Mr. Howard. A pine forest should offer the very best kind of a discharger yet lightning frequently strikes trees in such forests.

While it may not be possible to simulate all actual conditions in tests on models, it is felt that the result of such tests should be of very material help in laying out protective schemes. Perhaps the best that can be hoped for in most schemes that are economically feasible is that the hazard may be very greatly reduced.

CONTROLLING INSULATION DIFFICULTIES IN THE VICINITY OF GREAT SALT LAKE[1]

(HOWARD)

SALT LAKE CITY, UTAH, SEPTEMBER 9, 1926

W. C. Lee: Carrier-current systems are, in general, very sensitive to insulation conditions on the line, especially at frequencies above 10 kilocycles, and the value of washing insulators as a means of maintaining a high degree of insulation resistance west of Salt Lake City is demonstrated by the fact that our carrier telegraph system has operated for five years without a single interruption due to failure of the line to transmit sufficient current.

Of course the insulation resistance does drop in wet weather and during a recent storm it dropped to 0.4 megohm per mi., making necessary a 70 per cent increase in the repeater amplification to maintain a given current level at an average frequency of 20 kilocycles.

Had not a constant program of insulator washing been maintained, it is manifest that the carrier-current system could not have been operated in wet or foggy weather.

N. M. Johnson: In Mr. Howard's paper mention is made of the fact that other wire-using companies had experienced complete failure of telegraph lines in the vicinity of the Great Salt Lake Desert, due to very low insulation, particularly when heavy fogs prevailed. During my five years in Salt Lake, having to do with testing and handling of these lines, I have not found a single case where it was impossible to use either the telephone or telegraph circuits during the period of low insulation. It is true, however, that we have approached the danger point in some cases. Especially about the time the insulators are due for washing. The telegraph duplex sets operating on a normal current of 60 mils. line current has dropped to as low as 15 mils., but due to the differential type of duplex set in use at Salt Lake which operates on small current margin we have been able at all times to continue operation. Some rather severe crosstalk in the telephone circuits is associated with the low insulation; but in all cases this condition clears up rapidly as the insulation improves. It is, of course, difficult to get any sort of quick test when the lines are weather-crossed and distributed over a rather large territory. Our first test station in this section is at Wendover, about 130 mi. west of Salt Lake. Here we can open the lines and determine an approximate location of the trouble. It is my firm belief that if the insulators are not washed regularly every two years, we shall, as Mr. Howard states, encounter severe difficulties.

A. S. Peters: The difficulties in connection with the construction of the pole line across the flats were quite unusual. Owing to the mud of the flats and the constantly shifting water on the salt beds during all the year except about two months at the end of the summer, it is impracticable to do any extensive work except during this dry season. At this time, because of the heat and lack of precipitation, the salt beds are quite dry and a crust forms on the mud which will often support the workman.

At first, horses were used in connection with the work, but the hoofs would break through the crust, cutting the flesh above them, and the salt of the crust in the wounds soon caused such pains as to render the horses nearly useless.

During the summer the heat is intense, especially on the salt beds, because of the reflection from the crystalized salt. Workmen are compelled to wear colored glasses to protect the eyes. The perfectly level floor of salt or drab-colored mud makes a most monotonous landscape, broken only by a few hills in the distance. The only variations are the frequent mirages. A stray box thrown on the salt beds appears at a distance as a cabin.

B. F. Howard: In regard to Mr. Johnson's comments, I understood him to say that there had been no failure of the lines due to fallen insulation at any time. This would not have been the case had the insulators not been washed, for under certain weather conditions the lines would have undoubtedly been unusable.

Regarding Mr. Lee's remarks about the reason for raising the level of the "carrier," if the insulators had not been washed, I have no doubt that the lines could not have been used under the conditions which he mentioned. If the insulation falls as low as 0.4 megohm per mi., I should say that the insulators should be washed as soon as possible.

Since the time when Mr. Lee's discussion was presented at the convention, it has been ascertained that the low value of insulation alluded to was due to salt having been deposited upon some insulators on the line in a portion of the lead which is immediately south of Salt Lake and situated east of the mud flats. This portion of the lead had not previously been washed. After this was done the insulation of the whole lead rose to a satisfactory figure.

1. A. I. E. E. JOURNAL, December, 1926, p. 1268.

VACUUM-SWITCHING EXPERIMENTS AT CALIFORNIA INSTITUTE OF TECHNOLOGY

(SORENSEN AND MENDENHALL)

SALT LAKE CITY, UTAH, SEPTEMBER 7, 1926

Joseph Slepian: I was surprised when I read in Professor Sorensen's paper that he found very little pitting or vaporizing of the electrodes. It seems to me that this, if true, must call for some radical revision in our ideas of electric arcs.

As Professor Sorensen mentions in his paper, the most widely held theory of the arc requires that the cathode be maintained at a temperature sufficiently high for thermionic emission. I agree with Professor Sorensen that this theory is probably not correct and that a hot cathode is not essential for an arc. It is possible to have a high-current arc with a cold cathode.

Some most convincing evidence on this point published in the *Zeitschift fur Physik* is due to H. Solt, who caused a 10-ampere arc to move over a copper surface so rapidly that the copper did not get hot at any point.

I have repeated this experiment and I have caused arcs with as high as 20,000 amperes to move so rapidly over a copper ring that there was no visible melting of any kind.

But while it seems that a hot cathode is not necessary it does appear that in order to carry heavy current at low voltage a considerable pressure of gas or vapor of some sort is necessary. This gas or vapor would have to be supplied from the electrodes, and presumably in a successful operation of the switch this metal vapor would condense so rapidly at the zero of current that the high vacuum would be restored sufficiently to withstand the line voltage. But now, however, going by theory and by experience, to carry an arc of several thousand amperes will require a vapor pressure in the order of millimeters, and if the electrodes are to supply this vapor for a full half cycle, serious consumption of the electrodes will result.

If only a small amount of vapor in fact is formed, it would seem that the discharge must be of some very high-voltage form. I should like therefore to ask Professor Sorensen what the voltage on the arc was in his vacuum-switch experiments.

I should appreciate also some further information concerning the last switch mentioned in his paper, particularly how the moving electrode is brought into the vacuum tube.

D. C. Prince: The oscillograms shown in this paper indicate that in some way current is carried between the electrodes after they have separated until the termination of the half cycle. It is not necessary to assume that this current is thermionic.

The mechanism used to explain the cathode spot in the mercury rectifier might be applicable to this phenomena. It is briefly as follows: Electrons may be drawn from a relatively cool metal by an electric field of some millions of volts per centimeter. These electrons proceed until they strike neutral gas molecules, which they ionize. The positive ions so formed progress toward the cathode and set up, in this case copper, a high space-charge gra-

dient required to extract further electrons from the cathode material. The positive ions striking the copper surface heat it to the vaporizing point so that copper vapor is given off and is present to be ionized by the electrons.

In order that this action may take place in the extremely short distance required to give the potential gradient of millions of volts per centimeter, the copper vapor would have to have a pressure of the order of atmospheres in the neighborhood of the cathode. Upon the termination of a half cycle, the cathode spot would go out and there would be no mechanism to establish a cathode spot on the other electrode. Thus conductivity would be interrupted.

P. H. Thomas: Some years ago in the laboratories of the Cooper Hewitt Electric Company, I made rather extensive researches on the behavior of vacuum apparatus passing alternating currents, and arrived at a practical conception of these phenomena which may be of interest in connection with the further work of the authors. The question as to why the arc behaves as it does in a high vacuum is fundamental, of course, in considering what it is likely to do with heavier currents.

My conception of this phenomenon in 1906 is covered in a paper[1] presented before the A. I. E. E., May 31st, 1906, and is briefly as follows:

The electric current in a perfect vacuum is taken to be a stream of electrons, as with the bombardment in an X-ray tube. Once in the perfect vacuum, these electrons pass without resistance and without giving light or generating heat. To release such electrons carrying electric charges from a cold conducting surface in a perfect vacuum would theoretically require an infinite voltage. If, however, it be assumed that the flow of electrons has once been established (as by the well-known method of separating metallic contacts in the vacuum) it is reasonable to suppose that at the point on the cathode surface where the stream issues, an open door, so to speak, may be established in such a way that the assumed perfect surface of the metal is locally changed to give physically a *gradual transition* from a solid state to a gaseous state, then a comparatively small voltage would be sufficient to move electrons from the cathode to the vacuum space in accordance with the observed phenomena. To put it another way, the physical surface tension of the metal, taken in an electrical sense, is punctured at a certain spot by the passage of a certain amount of current and cannot heal until the stream stops, as at the zero point of an a-c. wave. As a matter of fact, if the current from a solid cathode once established in a perfect vacuum be gradually decreased in strength, a point will be reached at a strength of a few amperes at which it will snap out violently. In fact by using a series inductance in a d-c. circuit, a most excellent Wehnelt interrupter may be obtained, giving exceedingly abrupt high-voltage impulses.

According to this view the cathode spot from which the current issues in a perfect vacuum,—even from a solid electrode,—need not be a *hot* spot and, as a matter of fact, the phenomenon is much more easily explained if it be assumed cold. There is of course a brilliant light spot showing the excitation of the atoms at that point but the actual rise of temperature is probably small. This action is much clearer with mercury cathodes which cannot become heated on account of their power to evaporate but which exhibit the same switch action as the solid cathode.

This does not mean that arcs may not be fed by hot spots on cathodes, in *the presence of gases*. It seems probable that the critical feature of the vacuum switch which easily drops an arc at the zero point of the wave is the *cold* cathode, for such a cathode has no tendency to hold over the zero point, while the reason the arc in air does not drop out easily at the zero point is that the cathode spot is hot enough to emit electrons and stays so over the zero point.

The reason why the vaporization of copper at the cathode does not impare the vacuum would appear to be that copper is naturally a solid at ordinary temperatures and that any vaporized copper would immediately solidify and become inert. I believe that this type of circuit breaker will be very effective up to the point where in operation the vacuum does not deteriorate or the electrodes actually develop hot spots.

As a matter of fact, at the time of writing of the above paper, I operated vacuum switches in the laboratory for the purposes of investigation both with mercury and with solid electrodes, but not with such large quantities of energy nor so comprehensively as the authors.

Some of the specifications of patents on vacuum apparatus filed about this time and assigned to the Cooper Hewitt Electric Company would be of interest in this connection.

R. W. Sorensen: Dr. Slepian asked two or three definite questions. The first two switches were very poorly designed for practical operation; that is, the contacts were poor as judged by switch engineers and the solenoid coils around the neck of the switch, used to raise the plunger, were crude ones built by students inexperienced in the design of solenoids. These solenoids were weak and operated the plunger with a hesitating action. This uncertain action I am sure was the cause of many of the irregularities in the oscillograms made for switches 1 and 2. The poor operating mechanism in these switches was particularly noticeable in closing them. Switches No. 1 and No. 2 were closed by gravity when the solenoid circuit was opened. Such action of course caused the plunger to rebound several times at closing, thus causing an arcover each time the switch was closed, a very poor arrangement for a switching device.

We have shown no oscillograms for the switch closing, because there is no question as to its operation on closing. When the switch is closing, the contacts are absolutely cold and the insulation resistance of the vacuum space between switch terminals is so high that no arc can form between terminals when the switch is actually closed. This is frequently the case in an oil switch. Examination of the small switch shows that with all the ill treatment of the contacts for reasons just mentioned, there has been no appreciable pitting of the contacts. Switch No. 1 and also No. 2 has each operated according to our records more than 500 times. There were many additional operations of which no record was made. As stated in the paper, switch No. 3 is unique because in it we have found a means whereby we can bring the operating rods through the switch envelope and at the same time maintain a vacuum-tight envelope. The paper calls attention to the fact that switch No. 2 stood in the laboratory two months, disconnected and sealed off from the vacuum pump, before it was tried out at the Torrence Substation of the Southern California Edison Company.

Also I have used in calculations higher values for the amount of copper to be vaporized by a given amount of energy. The latest international tables of physical constants give 467 kw-sec. of energy required per gram molecule of copper, a much higher figure than the one we had been in the habit of using.

H. E. Mendenhall: Questions have been asked as to the theory of the vacuum switch but our work is in such an early experimental stage that we are not positive as to the exact mechanism of the high-vacuum arc.

Mr. Prince has suggested that the electrons to maintain the vacuum arc may be pulled out of the metal by very high electric fields as in the mercury rectifier. Dr. Slepian has asked what the voltage drop across the arc is. The voltage between the contacts at separation rises momentarily to some value below the maximum value of the voltage wave and then during the time of the arc there is apparently very little drop across the arc (less than in an oil switch). The arc goes out at the end of the first half cycle, at which time the voltage rises to a value less than 50 per cent above normal, the corresponding value for the oil switch being somewhat higher. The work of Millikan and Eyring has shown that potential gradients as high as 4,000,000 volts per

1. *Some Fundamental Characteristics of Mercury Vapor Apparatus*, A. I. E. E. TRANS., 1906, p. 601.

cm. are required to pull electrons out of metals up to 700 deg. cent. It is possible that the first electrons for starting the arc are pulled from the metal in the manner described by them, consuming a considerable portion of the voltage drop representing the energy dissipation in the arc, the balance of the drop going to vaporize and ionize enough copper atoms to establish conditions for thermionic emission for one half cycle. These conditions disappear with the recombination of the extremely short-lived metal ions and the reverse of the direction of current flow between switch terminals which from the physics point of view are electrodes whose separation distance is increasing during the opening of the switch.

We were very much interested in some work published by Dr. Slepian in which he advocated a rather new theory for the transition from glow to arc discharges. Instead of this transition being due to thermions from within the electrode, he reasoned that temperatures sufficiently high existed in the gas surrounding the electrodes to produce thermal ionization of the gas. From our work, in which we remove as much gas as possible and are thus able to extinguish the arc, we have concluded that the gases within the metal and absorbed on its surface in a layer perhaps only one molecule thick play an essential part in the maintenance of an arc.

We believe that the difference between our results and those mentioned by Dr. Slepian are due to a difference in the degree of vacuum attained in the two cases. We have used the latest high-vacuum technique so that although we have a so-called high vacuum of 10^{-6} mm. of mercury pressure, we have actually removed relatively few gas molecules, but we have increased very materially the mean free path of the molecules or the average distance one molecule will travel before it collides with another molecule. The importance of this factor becomes evident when we consider that an ion or electron may travel across the short distance between the electrodes of the switch in high vacuum without colliding with another molecule and thus ionization of additional gas molecules by collision is not likely to occur.

Mr. Thomas in his discussion assumes it is physically possible to obtain a perfect vacuum but we have already pointed out that there are numerically more gas molecules left in the evacuated chamber than have been removed.

The cathode spot which furnished electrons for one-half cycle becomes the anode when the voltage reverses and the new cathode is a relatively cold cathode so that electron emission from its surface cannot be started without intense bombardment by positive metal ions. We think that these same ions have had time to become ineffective due to recombination since their mean life is of the order of 10^{-8} sec.

We are not yet decided as to how all of the stored energy of the electric and magnetic fields, as roughly evaluated by Charpentier's formula, is dissipated, but our future program includes experiments which should determine better the principles involved in the operation of electric switches.

STABILITY CHARACTERISTICS OF ALTERNATORS[1]

(Shirley)

Salt Lake City, Utah, September 7, 1926

David Hall: As a designer of electrical machinery, I feel that this paper is valuable to the users of machinery because it points out some of the factors which are more or less concealed. We have specifications covering machines which do not cover the factors presented here and these factors are in many cases as important as the outstanding specifications of temperature and efficiency. We have pointed out in Mr. Shirley's paper certain "red flags" beyond which the designer knows his machine will "lie down." It is very useful to have those red flags placed before the designer.

The designer, as I see it, is a man who after, passing through a long period of designing, stands as near the precipice as he can without falling off. This paper points out that if he goes beyond certain factors he is liable to fall off and it is only through the rare judgment of good designing that he will stay at a respectable distance from the precipice. Those factors are hard to evaluate but the time will come when the user will be able to judge better of what he is buying and will not buy on price but on certain performance. I feel justified in making these remarks because we are all coming to understand machines very much better than we did a few years ago. Today we are reaching heights in designing which were not anticipated a few years ago. When I first read Mr. Shirley's paper I was a little fearful that he intended to have the Institute stipulate that a machine should not be built under a *certain ratio.* That probably does not come within the jurisdiction of the Institute because it wishes to prescribe a yard stick or measuring stick but not to establish the limits of that certain stick to a *certain ratio.* That work rests with the intelligence of the purchaser and the manufacturer.

H. V. Putman: I especially like the method used by Mr. Shirley. He has worked out the stability problem for a few typical cases. From these he draws general conclusions and constructs a formula for a desirable value of short-circuit ratio which will be of great value to all who have to do with the design and application of synchronous machines.

In several of the generator specifications received within the past year or two, by the Westinghouse Company, where the problem of stability has arisen, this company has been asked to guarantee the synchronous reactance of the machines. While it is true that the synchronous reactance is very closely tied up with the short-circuit ratio, it is highly desirable that the short-circuit ratio be the quantity guaranteed because it is much easier to define and is much more easily checked by test. You will note that Mr. Shirley has not mentioned synchronous reactance at all in his discussion. An agreement was recently reached between Westinghouse and General Electric engineers to the effect that in presenting generator propositions the short-circuit ratio should be stated instead of the synchronous reactance, except in special cases.

There is one question I should like to ask Mr. Shirley: Is it not true that if the load on an alternator is increased very suddenly it will carry loads considerably in excess of the values given by the curves shown in Figs. 6, 7 and 8 of the paper, which are all calculated upon the basis of steady-state conditions? I know of several synchronous motors that carry sudden peak loads, continually recurring, from 30 to 50 per cent greater than the steady pull-out torque of the motor. The reason for this is that the peaks take place so suddenly that the armature reactance does not have time to destroy the field flux so that, so far as the peak load is concerned, the machine acts as though it had a much higher short-circuit ratio than it actually has. Would not the same sort of thing, taking place in an alternator, enable it to maintain its voltage under a much higher load than it could under steady-state conditions?

I believe Mr. Shirley's bibliography should include the paper on the same subject by John Strasser, published in the August 1926 issue of the *Electric Journal.* Mr. Strasser has limited his discussion to the stability problem in turbo generators, but reaches practically the same conclusion as Mr. Shirley.

O. E. Shirley: Mr. Hall states that he does not consider it within the realm of the Institute to prescribe values of short-circuit ratio for which a machine should be designed, but that a standard of measuring stability should be given and then the users of the apparatus would be in position to determine the degree of stability required for their particular service. This is certainly quite proper for the larger installations, for which sufficient time can be given to determine the actual operating conditions, but for smaller machines, it may be desirable to establish a standard of stability, so that the purchaser may know that the characteristics of generators, built by different manu-

1. A. I. E. E. Journal, September, 1926, p. 813.

facturers, will not differ radically as may be the case if there are no standards.

In the case of important installations where individual characteristics of load and the generators are taken into account it is essential that there should be a common ground for specifying and comparing the stability characteristics of different machines. For these comparative purposes the criteria proposed in this paper should be satisfactory, but there still remain considerable knowledge and experience to be gained before it will be possible to specify the actual values of these factors to meet any given set of operating conditions.

Mr. Putman has brought up the point that the load limit of an a-c. generator for suddenly applied loads of short duration may be appreciably higher than the steady-state value. This appears to be quite reasonable for very short intervals of time, say 1 or 2 seconds, and for any particular machine it should be possible to obtain a curve between load limit and time of applying the load. This curve would start at a maximum value for a load lasting only a fraction of a second, and would decrease quite rapidly down to the steady-state value. The time at which it would practically reach the steady-state value would depend on the rate of change of the field flux and the stored energy of the rotating parts.

Since this paper was sent in for publication, an article, "Stability of A. C. Turbine Generators with Fluctuating Loads" by Mr. John Strasser has appeared in the *Electric Journal* for August 1926, and as suggested by Mr. Putman, this should be added to the bibliography.

FIRE PROTECTION OF WATER-WHEEL TYPE GENERATORS[1]

(Johnson and Burnham)

Niagara Falls, N. Y., May 28, 1926

Salt Lake City, Utah, September 8, 1926

(Discussion at Niagara Falls)

H. C. Don Carlos: We have found in some cases where machines were designed as semi-enclosed or totally enclosed machines that on account of the lack of fire protection it was necessary to change these to open-type machines, so that we could get to the fire to put it out in case of failure.

We have had several cases where windings have been completely destroyed. The damage is expensive and the outages are long.

On the other hand, with open-type machines we have had very few cases where the fire resulting from failure of coils has been very extensive. In most cases we have been able to control the fire, so that the damage is confined to a few coils in the immediate neighborhood of the failure.

In designing a system of protection there are several things to be taken into consideration.

In the first place, the system of protection must be such that it will not damage the entire winding, as has been suggested. The winding might as well be destroyed by fire as by the protection. While water protection may not permanently damage the entire winding it may damage it to such an extent that the outage will be intolerable.

B. L. Barns: I wish to point out that the illustrations which have been given of windings that were entirely destroyed by fire were of generators of the horizontal-shaft type having no provision for bringing them to rest quickly in emergencies of this nature. Vertical-shaft generators are usually provided with brakes by means of which it is possible to stop them in about three minutes.

H. U. Hart: I do not believe the method proposed counterbalances the danger of putting water connections in large high-voltage a-c. generators. I prefer the introduction of a fire-extinguishing gas to generators by means of storage tanks instead of a water sprinkler system which would cause damage to the high-voltage windings.

The damage to ends of coils due to fire in a-c. generators can be greatly minimized by using mica tape on the ends of the coils instead of cotton tape. The cost is greater, but this would lessen the amount of inflammable material.

R. B. Williamson: The method proposed in this paper is designed to do two things: One is to localize the flame by means of guards or baffles that force the air to flow in radial jets against the coils and prevent it from being swept around in a circle; the other is to localize the part wet by the water. In a great many cases where large machines have been wet all around it has been a very long, tedious job to get them dried out and any method that will limit the damage to a restricted area is highly desirable. In the early days of vertical machines no protection was provided in the way of brakes for shutting down promptly. I recall one instance of a slow-speed vertical machine of about 5000 kw., which had just been installed; in fact, it never had been on the load. When it was brought up to voltage it developed that there had been a connection damaged or broken in shipment which had not been detected, and this started a small arc which under the influence of the fans developed into a flame that swept around the winding and completely burned the insulation off the ends of all the coils. If the machine had been equipped with brakes they would have helped materially in limiting the damage. Of course brakes are now the universal custom on machines of this type. The limitation of the area in which the water is applied is very important, and the method described by Messrs. Johnson and Burnham is an excellent one for large water-wheel type generators.

L. W. Riggs: I should like to inquire if any one has had experience in applying carbon dioxide to such machines, that is, not including turbo alternators and, if so, what amount of leakage of air can be tolerated; how tight does the ventilation system have to be?

S. Q. Hayes: Bearing on this same subject it might be interesting to note that the Duquesne Light Company in Pittsburgh is using carbon dioxide in connection with the putting out of fires on some synchronous converters. If I remember correctly it has been figured that a mixture of about 20 per cent of carbon dioxide is sufficient to prevent the combustion being carried on. Up to the present time, the Duquesne Light Company has had no fire. They were just rearranging some of their synchronous converters, completely enclosing them, and they provided for this with the Lux Company in New York. They have a rather interesting scheme to automatically open a number of cylinders that will squirt carbon dioxide into this enclosed machine. They have it so arranged that the air circulation will be shut off automatically and the carbon dioxide turned on in case of trouble. I think there was a description in one of the recent technical papers prepared by one of the Duquesne Light Company's men covering this proposition.

These machines, so far as I remember, are 7500-kv-a., 60-cycle, synchronous condensers, fairly high-speed.

M. W. Smith: When carbon dioxide is used for extinguishing fires in rotating machinery it is common practise to close both the air inlet and air outlet in order to retain this gas within the machine. With the air outlet closed, the gas pressure, and consequently the leakage, increases. The amount of leakage will be influenced by the construction of the end-bell enclosures. One precaution that is usually taken in the application of carbon dioxide is to provide means for short circuiting the ventilating system after the normal inlets and outlets have been closed. This allows the gas to circulate internally from the outlet to the inlet, and the pressure is largely consumed inside the machine with the reult that the leakage is materially reduced.

H. C. Don Carlos: I should say that fires result from different causes. One common cause is poor connections at the end

1. A. I. E. E. Journal, November, 1926, p. 1121.

of the winding. These may escape detection on account of the insulation covering and the difficulty of inspecting all of the joints, which emphasizes the importance of extreme care in making up joints at the end of the windings.

Another cause, of course, is the failure of insulation, and extensive fires will usually result from the failure of insulation at the end of a winding. In my experience, failure of insulation in the slot is not likely to develop a serious fire.

James A. Johnson: That would indicate that the oily dust, or an accumulation of that nature, is not really the main item to be guarded against. The prevention of these fires really goes farther back,—before the machine even leave the plants. That is the proper time to put the preventive measures into effect.

L. W. Riggs: It seems to me that the operators have a great deal to do with the prevention of fires. I think they are not sufficiently diligent in finding loose connections.

Any oily dirt accumulated on the end windings should be cleaned off. In the first place it adds to the inflammability of insulation; and in the second place it plugs up the air ducts thereby allowing the machine to become much hotter than contemplated thus promoting the starting of fires. The operating force should not allow a machine to get dirty even if they feel that it will not catch fire.

There is another point which one of the speakers brought up in regard to the volume of air that is contained in the machine in a given instant. On high-speed synchronous machinery, it is surprising how little air there is in the machine at any one time. I think that most people would be surprised if they calculated the volume of air.

(Discussion at Salt Lake City)

E. H. Freiburghouse: Fires which are not caused by the electrical failure of the insulation sometimes occur; hence the system and equipment which Messrs. Johnson and Burnham describe would function in a desired manner whereas the common differential-relay system for the protection of a generator would not set in motion alarms or mechanisms for extinguishing fires until the insulation had arced through. Their system also has a very valuable feature whereby the application of water would be selective and localized to the actual fire area. Sprinkler heads could be made to act as relays in the application of carbon dioxide within totally inclosed generators of the steam turbine type and would protect the generator from fires originating in the surface of the insulation before electrical breakdown occurred.

I believe, however, that in most cases of fire within totally inclosed generators the carbon dioxide could and would be applied much more quickly by means of the electrically operated differential-relay system. Evidently protective equipment of the differential-relay type has prevented many fires even from starting. By opening the armature and field circuits most of the flux in the magnetic circuit is eliminated within one second and this extinguishes the dynamic arc within a second or two, whereas the data which the authors present indicate that it might be two or three minutes after the fire started before the sprinkler heads would operate.

Generators having open or semi-enclosed systems of ventilation which the authors have described do not readily permit of instantaneous flooding of the entire generator with carbon dioxide. Therefore, the detective feature of the sprinkler head and the localized application of water obtained by it are valuable.

We somewhat question the application of radial vanes in the discharge air from fans used in the ventilation of a generator since the vortex angle of the air leaving the fan blades is far from radial and would therefore make the ventilation system less efficient. This would be especially so in the case of high-speed turbine generators in which the ventilation is obtained by means of fans.

J. M. Buswell (communicated after adjournment): I shall be interested indeed in knowing whether the Johnson-Burnham scheme of baffling the stator frame so as to stop the hurricane produces a very noisy machine.

I am also interested in knowing if there have been any modifications to the method of applying those fire baffles and whether or not there has been any modification of suggestion as to the material of which these fire baffles may be made.

I have a further thought that the two- or three-minute period dealt with by Johnson and Burnham, in their paper, is sufficient to burn out the fire baffles themselves and produce a blast-furnace effect and that some more rapid fight against a fire will have to be provided.

It seems that there is some possibility that a modification of the Johnson-Burnham suggestion might work very well. Specifically, my thought is that by tilting the fire baffles slightly in the direction of the air currents thrown off by the rotor, there would not be so much air flutter and eddy; and then by arranging for the quick release of carbon dioxide or carbon tetrachloride in the section in which the fire occurs, we could get a combination faction which might be very effective.

I believe that the damaging fires which have occurred have swept around the armature and even before sweeping around the armature attained at the source a tremendously high heat in just a few seconds, and it is my belief that whatever fire fighting is done must be started immediately after the original arc starts, the first move, of course, being to kill the field and disconnect the armature, and by killing the field I mean not only disconnect ing it but actually killing it.

G. A. Fleming (communicated after adjournment): The research work in controling the spread of fire in generators through the proper design of air ducts as described by Messrs. Johnson and Burnham, is one more example of constructive thought in machine design, reducing operating troubles and the additions of undesirable accessories.

It is true that most water-wheel type generators employ an open or semi-enclosed system of ventilation, but two 45,000-kv-a. waterwheel-driven generators are now being installed by the Southern California Edison Company that will have a completely closed ventilating system similar to those used on turbo generators. Better fire protection was one reason for the choice of this system so a few remarks on the company's practise in arranging fire equipment should be of interest as discussion of this paper.

Carbon dioxide is used as the extinguisher medium and is injected as directly as possible into the enclosed air system. Since no damage is done to the generator by the CO_2 it is possible to arrange for its automatic release even with a relatively small increase in air temperature. Also, a scheme by which the differential-relay system for internal trouble will release the CO_2 when the machine is de-energized is being seriously considered for cases where too much outside equipment is not included in the differential loop. One present installation includes this feature but, due to unreliable relays, it has not been put in service.

The authors refer to the fact that the energy stored in the magnetic circuit makes it impossible to de-energize instantaneously a machine even with differential relays and therefore, it is impossible to prevent fire with them alone. But since the relays act ahead of the fire, it will surely be of tremendous advantage to have them open the fire extinguishers as well as all electrical circuits and thereby anticipate it as much as possible. It is our practise to arrange for an initial release of CO_2 under atmospheric pressure of approximately 50 per cent the volume of the ventilating system and to follow this with delayed charges at intervals timed to maintain a minimum 25 per cent saturation until there is no danger of the fire spreading or again starting from the rotation of the machine, or otherwise which we believe to be approximately 30 min. for a large generator. In the use of such a system it is of importance to have the ventilating system as tight as possible to prevent the escape of the CO_2 and

suction of outside air at points where the pressure is less than atmospheric pressures due to the fan action.

J. A. Johnson: The use of carbon dioxide in this type of machine where large volumes are involved will mean in many cases a change in the usual system of ventilation. A closed system of ventilation or a system of ventilation which can be converted quickly into a closed system appears at present to be necessary for the use of carbon-dioxide extinguishment. Completely open ventilating systems are impracticable in large vertical machines.

As to the question of brakes, with the system of air control described it probably is better to allow the machine to continue to rotate in order to maintain the radial movement of the air, as that in itself has the effect of limiting the spread of the fire. However, these machines are equipped with brakes and can be stopped if desired.

One of the fires shown in the pictures was caused by a fault between strands of one of the end connections which started a small arc inside of the insulation, developed sufficient heat to burn a hole through the insulation and started a fire. I am not sure about the other case.

It is quite true that oily dirt should be removed, as Mr. Riggs suggests. Under Niagara Falls conditions, however, with daily load factors above 90 per cent and even monthly load factors 85 per cent or higher, opportunities for shutting down for cleaning, involving dismantling to the extent necessary in machines of this character, without serious loss of revenue, do not occur as frequently as might be desired. Manufacturers can help by designing oiling systems which will not leak oil, and the baffles described in this paper will undoubtedly assist in depositing suspended oil and dirt before they reach the windings.

Mr. Freiburghouse and Mr. Buswell both question the use of radial vanes, one suspecting reduced efficiency and the other increased noise. Both of these suspicions are apparently based on a misconception as to the location of these vanes. They are not placed immediately in front of the fan blades, but either at some distance away or at the side, and pass only a small part of the air supplied by the fans. There is no particular virtue in *radial* vanes except that they are easy to make and serve well enough. Under certain conditions curved vanes might be better, the criterion being that the resulting air currents through the end windings shall be substantially radial or a combination of radial and axial but in no degree whatever circumferential. The installations described produce no noise and, we believe reduce losses by elimination of some unnecessary air movement.

In reply to Mr. Buswell's thought that the fire baffles themselves might be burned out it may be pointed out that the current of air through the baffles will blow the flame directly away from them, and that the air serves to keep the baffles themselves cool. Since the baffles are made of materials which will hardly support combustion, the only danger to them is the general rise of temperature in the compartment which might ultimately reach a value which could damage them. However, long before this condition could become serious the sprinkler heads will blow, the alarm be given, and extinguishing means be brought into play.

E. J. Burnham: The accompanying drawing shows a method of using fusible sprinkler heads in generators having a closed system of ventilation, such sprinkler heads being used for detecting fire and causing, at the same time, automatic release of CO_2 into the ventilating system. Refering to the drawing, notice that air pressure is normally kept on the sprinkler system, and that the operation of a sprinkler head causes a reduction in pressure in the piping system, thereby causing the contacts on the pressure gage to close, which, in turn, operates an electrical release, this causing a weight to drop, that lets the CO_2 into the generator ventilating system. In using this scheme for releasing CO_2, suggestion was made that the generator differential relays be connected so that either the operation of a sprinkler head, or operation of the differential relays would automatically release the CO_2.

Referring to Mr. Hart's discussion, he states that he prefers the use of a fire-extinguishing gas, to water, Also, Mr. Buswell suggests the possible modification in baffles, with arrangement so that CO_2 may be quickly released in sections where fire is located. I wish to point out that we are not proposing to use the sprinkler method of extinguishing fires where the CO_2 method can be easily applied, but rather, for use with large, vertical, slow-speed generators using open-type ventilation, where the use of CO_2 would be very ineffective.

Mr. Freiburghouse, in his discussion, states that in most cases

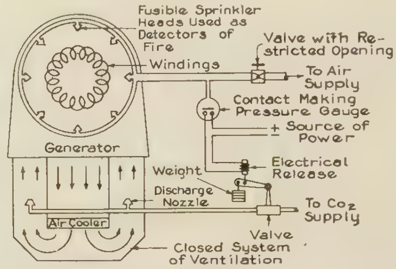

FIG 1.—DIAGRAM OF FIRE PROTECTION OF GENERATORS

of fires in enclosed generators, CO_2 would be applied quicker by relays than by sprinkler heads. The sprinkler-head method of releasing CO_2 in generators having a closed system of ventilation is not expected to supersede the method by which the CO_2 is automatically released by the differential relays. It is suggested that the two methods be combined so that CO_2 will be released for surface fires, or other cases in which the relays fail to function before damage becomes excessive.

Discussion at New York Meeting

FREQUENCY MEASUREMENTS WITH THE CATHODE-RAY OSCILLOGRAPH[1]

(RASMUSSEN)

NEW YORK, N. Y., NOVEMBER 12, 1926

T. E. Shea: Mr. Rasmussen has discussed the need for accurate and ready measurements of frequency. It is rather difficult to overstress the importance of frequency as an engineering variable in communications work, for the whole transmission problem centers about the signals we want to transmit and the interference we don't want to transmit. Both the signals and the interference are made up of a large number of frequency components and so the vital transmission characteristic of communication networks may be said to be frequency characteristics. We have frequency against impedance, or reflection coefficient; frequency against transmission loss, or attenuation; frequency against phase shift, and so on—always frequency against some other variable.

This is well illustrated in the case of wave filters. It is the function of wave filters to separate bands of frequencies and for economic reasons relatively small frequency intervals can be allowed for filter characteristics—in this case transmission-loss characteristics—to change from free transmission regions to regions of high attenuation or inefficient transmission. Here is where accurate and ready frequency measurements are of great assistance, in insuring that filter characteristics embodied in some physical network are accurately placed along the frequency spectrum so that the signal frequencies pass through as efficiently as possible and the interfering frequencies are barred out.

1. A. I. E. E. JOURNAL, January, 1927, p. 3.

It is usual in discussing wave filters to stress the large amount of network theory and the extensive calculations involved in their design but one can readily see than an economic balance would hardly be struck if great effort were put into working out theoretical designs and an equal effort were not put into the development of measurement methods so that proper guide posts were not available at all times to indicate how far the theoretical designs had any value. This is as a matter of fact an indication of the importance of measurement methods such as Mr. Rasmussen describes—that they are the guide posts to us without which design work would be of little avail.

LIGHTING OF RAILWAY CLASSIFICATION YARDS[1]

(Johnson)

New York, N. Y., November 12, 1926

J. A. Summers: One of the difficulties in yard lighting is that space where towers or projectors may be located is valuable. The lighting of the area in the yard itself is very simple, but there are many problems which must be overcome in connection with glare and location of projectors. The intensity may be as low as 0.21 foot-candle. With such low intensities and poor reflection factors from the cars, the problem is not so simple as that of lighting an open space.

If the ends of the cars had white targets across them,—a circle or a band,—it would help the visibility very materially. Such targets could be painted on when the cars are brought in for repairs.

R. W. Cost (communicated after adjournment): The method of yard lighting as outlined by Mr. Johnson is known as "unidirectional" and provides illumination in the direction of traffic primarily to avoid glare to the operators. Another arrangement of projectors known as the "parallel-opposing" system is widely used by railroads in yards employing hump riders and equipped with automatic switches. It consists essentially of opposing projectors banks with four to eight 1000-watt units mounted on towers at least 70 ft. in height and spaced 2500 ft. to 5000 ft. apart. With this system the opposing beams provide more even distribution of light over the entire yard and objects are visible either by direct reflection or in silhouette, depending on the position of the observer in the yard. When traffic moves in the face of projected light there is, of course, the disadvantage of possible glare but it can be minimized if the trainmen wear vizored headgear.

Mr. Johnson states that power for lighting decreases proportionally as the yard decreases in length. As the total wattage or lumen requirements for a yard are usually in proportion to its area, it would also be necessary to take into consideration the yard width as well as its length. The Association of Railway Electrical Engineers, whose Committee on Illumination has made a rather extensive investigation of this subject, advocates the use of 0.1 lumen per sq. ft. of yard. Only the available lumens in each projector beam, which vary from 35 per cent to 45 per cent of the generated lumens, can be used in calculating the total wattage required.

Where a classification yard is built on a curve the number and location of floodlighting projectors will vary somewhat from the arrangement in a straight yard of the same area if light distribution and illumination between car tracks are to be comparable.

G. S. Johnson: With reference to Mr. Cost's discussion, I discussed that in the main body of the paper, and mentioned the fact that I believed it impractical for the men to wear visors. I did not discuss silhouette lighting, as at the present time this has not been developed to a point where we consider it a good practical proposition. It has considerable merit and undoubtedly will be used to some extent in the future when a means has been developed to obviate the glare.

1. A. I. E. E. Journal, January, 1927, p. 33.

ILLUMINATION ITEMS

By Committee of Production and Application of Light

ILLUMINATING ECONOMICS IN GERMANY

In June 1926 C. P. Jensen, Managing Director of the Osram Company, Berlin, lectured at Wiesbaden before the 31st Congress of the Association of German Engineers. Mr. Jensen stated that the "aim of illuminating economics is to treat light economically like any other raw material and to see to it that the expenses for light are compared with the useful effect obtained and examined as to their justifiability in order to avoid wasteful and extravagant management either from a misinterpreted sense of economy and thrift or prodigality."

While pointing out the profitable results to the makers of electrical machinery and lighting equipments, he emphasized the relatively greater benefit conferred upon the public, through a more liberal economic use of light. "At present nearly 6000 different types and finishes of electric incandescent lamps have to be produced, kept in stock and distributed, and it is self-evident on the face of it how greatly costs could be reduced if this multiplicity could be reduced to a portion of the present total." As a first step a simplified series of six lamps apparently corresponding to the so-called simplified line in the United States is being introduced. Recommendations are made for a revision of rates for electricity with regard to demand, so as to be more in line with cost of production, and encourage more extensive use. Increased demand will bring further economics of production.

The waste due to improper design and selection of lighting fixtures is discussed; also the need of replacing obsolete types. Reference is made to the educational work carried on in the Light House (the Lighting Institute of Berlin). Effort is being made to train a staff of men, to carry on the educational work throughout Germany.

Among the groups who have received instruction at the Light House are 400 wiremen, 160 members of the Association of the German Lighting Trades, 70 electricity works engineers of Berlin (Association of Electricity Works of German Illuminating Engineering Society) and 100 directors, managers, engineers and officials of electricity works throughout Germany. Over 430 demonstration lectures have been given in the Light House and elsewhere in various cities.

It is proposed to form a German Society for Illuminating Economics, an important service especially in view of the existing economic distress.

Cooperation has been established with the Chief Association of the German Retail Trade, The Associated Lighting Trades of Germany, The Association of German Electro-Installation Firms, the Association of German Advertising Experts, Union of Show Window Decorators of Germany.

A central organization cooperating with the above named groups is undertaking a canvassing campaign for better lighting of show windows.

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Changes of advertising copy should reach this office by the 15th day of the month for the issue of the following month.

The Institute is not responsible for the statements and opinions given in the papers and discussions published herein. These are the views of individuals to whom they are credited and are not binding on the membership as a whole.

The Winter Convention February 7-11

Plans for the Winter Convention of the Institute to be held in New York February 7-11 have been completed and the advance registration indicates a large attendance. The Engineering Societies Building, 33 West 39th Street, will be headquarters for the convention.

The technical sessions will be especially good and there will be other features of unusual interest. Among the technical subjects will be the following: synchronous-machine analyses; synchronous-converter theory; losses in constant-current transformers, in synchronous machines and in armatures; plotting magnetic fields; reactances which carry direct current; standardization of power-system voltages; cable characteristics; oil breakdown; dielectric absorption; corona space charge; circuit-breaker tests; surges on transmission lines and cables; rectifiers of electronic type; telephony and telegraphy; wire-drawing mills; a-c. elevators; and meter calibration and temperature compensation.

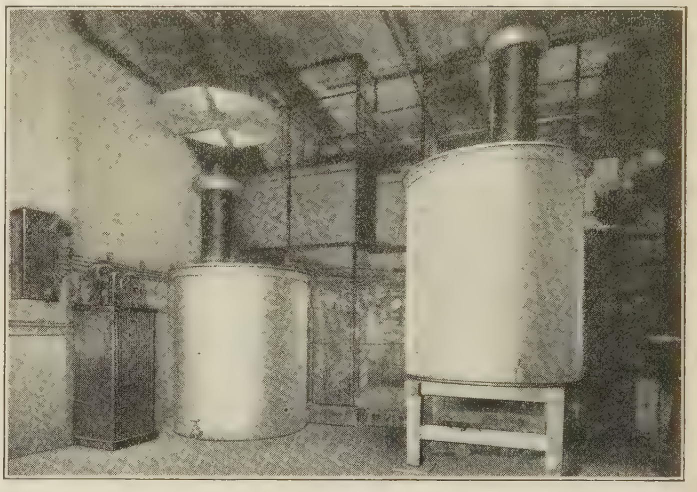
A smoker will be held on Monday evening, February 7, in the Hotel Astor. Entertainment will be provided by some excellent performers and a late supper will close the evening. Graham McNamee, of broadcasting fame, will be master of ceremonies.

The dinner-dance at the Hotel Astor on Wednesday evening will be a most pleasurable occasion for those who attend. Dinner will be served in the ball room of the Astor and afterwards Paul Whiteman's Picadilly Players will offer the music for dancing.

A large number of inspection trips are being arranged to places of engineering and of general interest. Among the visits which are planned are those to the following: The East River Station of the New York Edison Company, Hudson Avenue Station of the Brooklyn Edison Company, the Electrical Testing Laboratories, Station W. E. A. F. of the National Broadcasting Company, transmission of pictures over wires by the American Telephone and Telegraph Company, the Bell Telephone Laboratories, a machine-switching board of the New York Telephone Company, the New York-New Jersey Vehicular Tunnel, the Lighting Institute of the Edison Lamp Works, supervisory-control substations of the Staten Island Edison Company.

The local arrangements for the meeting have been in the competent hands of the following committees:

General Committee: Messrs. G. L. Knight, Chairman; H. H. Barnes, Jr., J. B. Bassett, H. P. Charlesworth, H. A. Kidder, R. R. Kime, E. B. Meyer and C. E. Stephens.



High-Voltage Testing Equipment at Electrical Testing Laboratories

Entertainment Committee: Messrs. C. E. Stephens, Chairman; J. B. Bassett, H. B. Coxhead, C. M. Gilt and H. A. Kidder.

Dinner-Dance: Messrs. J. B. Bassett, Chairman; S. P. Grace, E. E. Dorting, H. C. Dean, L. B. Bonnett, C. R. Jones, J. F. Kelley and F. A. Muschenheim.

The Vehicular Tunnel Under the Hudson River

Smoker: Messrs. H. B. Coxhead, Chairman; C. M. Gilt, E. C. Soares, I. W. Green, C. W. Franklin and J. F. Fairman.

Inspection Trip: Messrs. A. H. Inglis, Chairman; R. W. Conwell, W. B. Kirke, F. H. Stoppelman, G. S. Rose, G. C. Hall and V. J. F. Brain.

The following is the schedule of events for the convention:

PROGRAM OF WINTER CONVENTION FEBRUARY 7-11, 1927

MONDAY MORNING, FEBRUARY 7

Registration
Committee Meetings

MONDAY, 2:00 P. M.

TECHNICAL SESSION

SYNCHRONOUS ELECTRICAL MACHINES

Synchronous Machines—III, by R. E. Doherty and C. A. Nickle, General Electric Co.

Sub-Synchronous Harmonics on M. M. F. Wave of Polyphase Windings, by Quentin Graham, Westinghouse Electric & Mfg. Co.

Transverse Reaction in Synchronous Machines, by J. F. H. Douglas, Marquette University.

Starting Performance of Synchronous Motors, by H. V. Putman, Westinghouse Electric & Mfg. Co.

MONDAY, 8:00 P. M.

SMOKER AND ENTERTAINMENT

TUESDAY, 10:00 A. M.

TECHNICAL SESSION

ELECTRICAL MACHINERY

(SYNCHRONOUS CONVERTERS AND LOSSES)

The Synchronous Converter—Theory and Calculations, by T. T. Hambleton and L. V. Bewley, General Electric Co.

Constant-Current Regulating Transformer Characteristics, by H. C. Louis and Arthur Albaugh, Consolidated Gas, Electric Light & Power Co.

Additional Losses of Synchronous Machines, by C. M. Laffoon and J. F. Calvert, Westinghouse Electric & Mfg. Co.

Reduction of Armature Copper Losses, by Ivan H. Summers, General Electric Co.

AN 80,000-KW. TURBO GENERATOR SET IN THE HUDSON AVENUE GENERATING STATION

TUESDAY, 2:00 P. M.

TECHNICAL SESSION

MAGNETIC FIELDS AND REACTANCES

Graphical Determination of Magnetic Fields
Three Papers as Follows:

(*a*) *Theoretical Considerations*, by A. R. Stevenson, Jr., and R. H. Park, General Electric Co.

(*b*) *Comparisons of Calculations and Tests*, by E. E. Johnson, General Electric Co., and C. H. Green, Raytheon Mfg. Co.

(*c*) *Practical Applications to Salient-Pole Machines*, by R. W. Wieseman, General Electric Co.

Design of Reactances and Transformers Which Carry Direct Current, by C. R. Hanna, Westinghouse Electric & Mfg. Co.

WEDNESDAY, 9:30 A. M.

TECHNICAL SESSION

VOLTAGE STANDARDS

Voltage Standardization of A-C. Systems from the Viewpoint of the Electrical Manufacturer, by H. R. Summerhayes, General Electric Co., and F. C. Hanker, Westinghouse Electric & Mfg. Co.

Voltage Standardization From a Consulting Engineer's Point of View, by R. E. Argersinger, Stone and Webster, Inc.

Standardization of Voltage Ratings for A-C. Power Systems and Equipment, by A. E. Silver and A. L. Harding, Electric Bond and Share Co.

Voltage Standardization as Related to Distribution Systems, by H. B. Gear, Commonwealth Edison Co.

A BROADCASTING STUDIO OF STATION W E A F

Voltage Standardization and Its Relation to the Interconnected Companies of the Southeast, by H. J. Scholz, W. W. Eberhardt and S. M. Jones, Alabama Power Co.

The Suggested Transformer Voltage Standards and Their Relationship to Pacific Coast Practise, by Pacific Coast Electrical Association Subcommittee on Transformer Standardization, H. H. Minor, Chairman.

Standardization of Voltages, by A. Huber-Ruf, Brown Boveri Co. (Switzerland.)

Combined Light and Power Systems, for A-C. Secondary Networks, by Henry Richter, Westinghouse Electric & Mfg. Co.

WEDNESDAY, 2:00 P. M.

TECHNICAL SESSION

CABLES, DIELECTRICS AND CORONA

A New 132,000-Volt Cable Joint, by D. M. Simons, Standard Underground Cable Co.

Oil Breakdown at Large Spacing, by D. F. Miner, Westinghouse Electric & Mfg. Co.

Maxwell's Theory of the Layer Dielectric, by F. D. Murnaghan, Johns Hopkins University.

Space Charge and Current in Alternating Corona, by C. H. Willis, Princeton University.

WEDNESDAY, 7:00 P. M.

DINNER-DANCE

THURSDAY, 10:00 A. M.

INSPECTION TRIPS

THURSDAY, 2:00 P. M.

TECHNICAL SESSION

CIRCUIT BREAKERS AND SURGE INVESTIGATIONS

Tests on Oil Circuit Breakers, by Philip Sporn and H. P. St. Clair, American Gas and Electric Co.

Klydonograph Surge Investigation, by J. H. Cox, P. H. McAuley and L. G. Huggins, Westinghouse Electric & Mfg. Co.

Transmission-Line Voltage Surges, by J. H. Cox, Westinghouse Electric & Mfg. Co.

The Measurement of Surge Voltages on Transmission Lines Due to Lightning, by E. S. Lee and C. M. Foust, General Electric Co.

FRIDAY, 10:00 A. M.

PRESENTATION OF JOHN SCOTT MEDAL

TECHNICAL SESSION

TELEPHONY, TELEGRAPH AND WIRE MILLS

A New Electronic Rectifier, by L. O. Grondahl and P. H. Geiger, Union Switch and Signal Co.

Measurement of Telegraph Transmission, by H. Nyquist, R. B. Shanck and S. I. Corey, American Telephone & Telegraph Co.

Telegraph Traffic Engineering, by H. Mason and C. J. Walbran, Western Union Telegraph Co.

Developments in the Manufacture of Copper Wire, by J. R. Shea and Samuel McMullan, Western Electric Co.

TELEPHOTOGRAPH APPARATUS AT PLANT OF AMERICAN TELEGRAPH & TELEPHONE COMPANY

FRIDAY, 2:00 P. M.

TECHNICAL SESSION

A. C. ELEVATORS, METERS AND RECTIFIERS

A-C. Elevator Motor Drive, by E. B. Thurston, Haughton Elevator and Machine Co.

A Stroboscopic Method of Calibrating and Checking Watthour Meters, by H. P. Sparkes, Westinghouse Electric & Mfg.Co.

Compensation of Temperature Errors in A-C. Watthour Meters, by D. T. Canfield, Purdue University.

The Kansas City Regional Meeting March 17-18

The first Regional Meeting of District No. 7 of the Institute will be held in Kansas City on March 17 and 18. Headquarters will be in the Kansas City Athletic Club, 11th and Baltimore Streets, where all the sessions will be held. A program containing a variety of technical subjects, as well as a banquet and inspection trips, has been arranged.

A conference of the Branch Counselors of District No. 7 will be held on March 16, the day previous to the formal opening of the regional meeting.

There will be four technical sessions and the papers will cover the following subjects: Resistance modulators, railway signaling, automatic substations, mercury rectifiers and applications of electricity in the oil industry and in flour mills.

On the inspection trips which have been arranged visits will be made to flour mills and to automatic substations. Other trips to the points of interest in and around Kansas City may be made by visitors if desired.

On the evening of March 17 a banquet will be enjoyed and one of the most prominent men of the Southwest will be the principal speaker.

Special plans are being made for the pleasure of the ladies who attend the meeting and it is hoped that many will be present.

The plans for the meeting are being carried out by several energetic committees as indicated below.

General Committee: A. E. Bettis, Vice-President in Seventh District; Henry Nixon, Secretary of Seventh District; R. L. Baldwin, G. O. Brown, S. M. DeCamp, E. R. Page and L. N. Van Hook.

Entertainment Committee: William M. Hand, Chairman; John W. Carrothers, Henry H. Kuhn, Arthur L. Mullergren, Mrs. Robert L. Conlin, Mrs. A. E. Bettis, Mrs. Henry Nixon and Mrs. R. L. Baldwin.

Reception Committee: M. M. Boggess, Chairman; R. L. Baldwin, S. M. DeCamp, George S. Gillespie, Wm. Hand, A. L. Mullergren, A. L. Maillard, Henry Nixon and J. F. Porter.

Transportation Committee: Thomas B. Bash, Chairman; Braxton Blasser, T. G. Hieronymus and John E. Launder.

Hotel and Registration Committee: George Fiske, Chairman; W. O. Edwards and W. J. Squire.

Attendance and Publicity Committee: T. C. Ruhling, Chairman; J. E. Busher, Bruce E. Dolch, B. J. George and Herman C. Henrici.

Speakers and Technical Meeting Committee: Glen S. Morris, Chairman; G. H. Ahlborn, M. M. Boggess, D. D. Clarke, Albert L. Maillard, E. R. Page, C. E. Reid, Geo. C. Shaad and M. P. Weinbach.

Finance Committee: J. F. Porter, Chairman; H. W. Eales, W. M. Hand and Henry Nixon.

PROGRAM OF THE KANSAS CITY MEETING

WEDNESDAY, MARCH 16

2:30 P. M. Branch Counselors' Conference

THURSDAY, MARCH 17

9:00 A. M. Registration

10:00 A. M. Address of Welcome, by A. E. Bettis, Vice-President of District No. 7, A. I. E. E.

10:30 A. M. Technical Session

Current Analysis in Circuits Containing a Resistance Modulator, by L. S. Grandy, University of Missouri

Development of Railway Signaling, by T. S. Stevens, Atcheson, Topeka and Santa Fe System

2:00 P. M. Technical Session (Automatic Substations)

A 21000-Kv-a. Automatic Substation, by D. W. Ellyson, Kansas City Power and Light Co.

Testing, Inspecting and Maintaining Automatic Stations, by Chester Lichtenberg, General Electric Co.

Carrier-Current Selector Supervisory Equipment, by C. E. Stewart and C. F. Whitney, General Electric Co.

2:00 P. M. Inspection trip to flour mills

6:30 P. M. Banquet

FRIDAY, MARCH 18

9-00 A. M. Technical Session (Mercury-Arc Rectifiers)

Mercury-Arc Rectifiers, by O. K. Marti and Harold Winograd, American Brown-Boveri Co.

Steel-Tank Mercury-Arc Rectifiers, by E. B. Shand, Westinghouse Electric & Mfg. Co.

Application of Mercury Arc Power Rectifiers, by C. A. Butcher, Westinghouse Electric & Mfg. Co.

2:00 P. M. Technical Session (Oil and Flour Industries)
Application of Electric Power to the Petroleum Industry, by B. K. Howard, Texas Power and Light Co.
Electric Welding of Pipe Lines in the Field, by J. F. Lincoln, Lincoln Electric Co.
Electricity in the Drilling of Oil Wells, by L. J. Murphy, Westinghouse Electric & Mfg. Co.
Electrification of Flour-Mill Industry, by Grover C. Meyer, Kansas City Power and Light Co.
2:00 P. M. Inspection trip to automatic substations.

Date of Bethlehem Regional Meeting Changed to April 21-23

The date of the Regional Meeting which will be held in Bethlehem, Pa., under direction of District No. 2, has been postponed to April 21-23.

A very interesting program is planned for this meeting including technical papers in a wide variety of subjects, a dinner and several inspection trips.

For the technical sessions papers on the following subjects are planned: mercury rectifiers, intercommunication in industrial plants, effects of lightning on transmission lines, electric transients, oil circuit breakers, reducing losses in electrical systems, voltage standardization, induction motors, and the application of electricity in steel mills, cement mills and coal mines.

On the evening of April 21 there will be a dinner and it is planned to have as the principal speaker H. M. Aylesworth, president of the National Broadcasting Company.

More details on this meeting will be published in the March issue of the JOURNAL.

Regional Meeting at Pittsfield, Mass. May 25-27

Pittsfield, Mass., will be the location of this year's regional meeting of District No. 1 which will be held on May 25, 26 and 27.

A program is being planned which will be announced at a later date. A number of interesting technical sessions are contemplated as well as other events.

One feature of the meeting will be the participation of the Student Branches of this District. At least one session will be devoted to student papers and conferences of students and counselors will be held.

Future Section Meetings

Akron

Electrification of the Rubber-Reclaiming Industry, by A. P. Regal, Philadelphia Rubber Co. February 18.

Starting of Large A-C. Motors, by P. C. Jones, The Goodyear Tire and Rubber Co. March 18.

Cleveland

Arc Welding, Its Present and Future, by J. F. Lincoln, Lincoln Electric Co. February 24.

Moving Traffic with Light, by Carl E. Egeler, Nela Park. Other phases of the subject will be given by representatives of The City, The Railway Co., and The Auto Club. Joint meeting with Illuminating Engineering Society. March 24.

Columbus

Electric Ship Propulsion. February 25.

Banquet Meeting. March 25.

Pittsburgh

Tide-Power Dreams Are Coming True, by Dexter P. Cooper. February 8.

Pittsfield

Relaying of Power Systems, by Robert Treat, General Electric Co. February 8.

Petroleum, by R. L. Welch, Secretary, American Petroleum Institute. February 15.

Electron Theory. March 8.

St. Louis

Recent Developments of the Telephone Industry, by a member of the Bell Telephone Laboratories. February 16.

Railway Electrification, by Dr. W. H. McClelland, McClelland & Junkersfeld, Inc. (Past President A. I. E. E.) March 16.

Schenectady

Opportunities in the Application Engineering Departments. Symposium by Messrs. R. C. Muir, H. H. Dewey, and H. L. Andrews, General Electric Co. February 4.

Sharon

Gas-Electric Locomotive. March 1.

Steel-Mill Electrification. April 5.

Vancouver

Idiosyncrasies of Railway Motors. March 1.

Hydroelectric Developments of the East Kootenay Power Company, by M. L. Wade. April 5.

Institute Prizes

The following announcement relates to the annual prizes for authors of papers presented at meetings of the Institute, and includes details of procedure, relative to submitting papers in the various competitions, as approved by the Board of Directors and applying to papers presented during the year 1926 and thereafter.

NATIONAL PRIZES

The following National Prizes may be awarded each year:

1. Best Paper Prize
2. First Paper Prize
3. Best Regional Paper Prize
4. Best Branch Paper Prize

a. The "Best Paper Prize" shall be awarded the author or authors of the best original paper presented at any meeting of the Institute.

b. The "First Paper Prize" shall be awarded the author or authors of the most worthy paper presented at any meeting of the Institute, provided the author or authors have never previously presented a paper before the Institute.

c. The "Best Regional Paper Prize" shall be awarded the author or authors of the best paper presented at any Regional or Section meeting of the Institute.

d. The "Best Branch Paper Prize" shall be awarded the student author or authors of the best paper presented at a Branch, or other student meeting of the Institute by a member of an Institute Branch.

e. The fundamental consideration in the award of the National Prizes, is the quality of the contribution made for the advancement of electrical engineering.

f. All papers submitted for prizes (excepting for the Branch Paper Prize) must be written by members of the Institute, and when papers are written jointly at least one of the authors must be a member of the Institute, and the cash value of the prize shall be divided.

g. All papers presented at any national meeting will be considered by the Committee on Award without being formally offered for competition. Papers other than those presented at national meetings and all "First" papers must be submitted, in triplicate, with a written communication to the National Secretary, on or before February 15th of the year following the calendar year in which they were presented: this may be done by the author or authors, by an officer of the Institute, or by the executive committees of Sections or Geographical Districts. As a normal procedure, papers submitted for prize awards, which were presented at Regional, Section, or Branch meetings, shall be submitted through the executive committees of the Geographical Districts.

h. All prizes shall be awarded for papers presented during a calendar year.

i. All National Prizes shall be awarded prior to May 1st each year, by the Committee on Award of Institute Prizes. This committee consists of the chairmen of the Meetings and Papers, Publication, and Research Committees, and such others as the Board of Directors may designate.

j. A cash prize of $100.00 and a certificate of award shall be given to the author or authors of each paper receiving a prize. At the discretion of the Committee on Award of Institute Prizes, any prize award may be omitted in any year in which at least three papers are not submitted in competition for the prize. Also, at the discretion of this committee, a single paper may be awarded more than one of the prizes available, and honorable mention may be made of papers which did not receive awards.

k. All prizes shall be presented at the Annual Convention of the Institute in June of the year following the year during which the papers were presented.

l. Papers awarded prizes shall be published in full or in abstract, in the Journal, in the Transactions, or in pamphlet form.

Regional Prizes

The following Regional Prizes may be awarded each year in each Geographical District of the Institute.

1. Best Paper Prize
2. First Paper Prize
3. Best Branch Paper Prize

a. The "Best Paper Prize" shall be awarded the author or authors of the best paper presented at Regional, Section, or Branch Institute meetings in the District.

b. The "First Paper Prize" shall be awarded the author or authors of the best paper presented at an Institute meeting in the District, provided the author or authors have never before presented a paper before the Institute at any National, Regional, or Section meeting.

c. The "Best Branch Paper Prize" shall be awarded the student author or authors of the best paper presented at a Branch, or other student meeting of the Institute by a member of an Institute Branch.

d. Papers must be submitted in duplicate, by the authors or by the officers of the Branch, Section, or District concerned, to the District Committee on Awards, on or before January 10th of the year following the calendar year in which the papers have been presented.

e. All papers submitted for prizes (excepting for the Branch Paper Prize) must be written by members of the Institute, and when papers are written jointly at least one of the authors must be a member of the Institute, and the cash value of the prize shall be divided.

f. Regional Prize awards shall be made prior to May 1st each year, by the District executive committees, or by another committee appointed by the District executive committee.

g. Each prize shall consist of $25 from the national treasury, and a suitable certificate of award issued by the officers of the Geographical District concerned.

A. I. E. E. Standards, No. 33, Electrical Measuring Instruments Now Available

A new section of the A. I. E. E. Standards, No. 33, Electrical Measuring Instruments is now available in final approved form. It was adopted by the Board of Directors, December 10, 1926 and is to become effective April 1, 1927. The standards in this section apply to the following kinds of indicating electrical instruments for direct and alternating current: Ammeters; voltmeters; wattmeters; reactive volt-ampere meters; frequency meters; power-factor, reactive factor and phase-angle meters; synchroscopes.

These standards are not intended to apply to indicating instruments provided with arrangements for curve drawing, contact making, etc. They do not apply to the following kinds of instruments:

(a) Small instruments of types and sizes which are used where low cost is essential; for example, small polarized-vane ammeters used on automobiles, battery-charging outfits, etc.

(b) Instruments constructed for very special requirements.

The following subjects are dealt with: definitions, rating, heating, characteristics, dielectric tests, insulation resistance and construction. Copies of the pamphlet may be obtained at a cost of 30 cents with 50% discount to A. I. E. E. members.

Correction in Proposed Revision of A. I. E. E. Standards for Alternators

In the January 1927 Journal, page 82, a proposed revision of A. I. E. E. Standards for Alternators, Synchronous Motors and Synchronous Machines, Section 7 of the Standards, is outlined. Through an error the formula for natural frequency appeared without the radical sign. It should have been expressed as follows:

$$F \frac{266{,}500}{\text{R. P. M.}} \sqrt{\frac{P_s \times f}{W\, R^2}}$$

The synchronizing power should be designated by P_s instead of P as published.

Coolidge Declines Medal

The Edison Medal which was awarded in December to Dr. William D. Coolidge "for the origination of ductile tungsten and the fundamental improvement of the X-ray tube," has been declined by Dr. Coolidge, for the reason given in the following letter:

Schenectady,
January 17, 1927.

Mr. Gano Dunn, Chairman,
Edison Medal Committee,
American Institute of Electrical Engineers,
New York City.

My dear Mr. Dunn:

Judge Morris has just handed down a decision to the effect that my ductile tungsten patent is invalid. This decision, coming from a man of Judge Morris' standing, proves to me that the best of men could question my right to the Edison Medal which your Committee has been good enough to award to me.

My appreciation of that great pioneer, Mr. Edison, in whose honor the medal was established, and my admiration for its former recipients, are such that I would not, for the world, do anything that could in any way detract from the lustre of that medal, which should stand for generations to come as one of the most coveted prizes for meritorious work in the electrical field.

In the light of the above facts, I cannot accept the medal.

Allow me to take this opportunity to thank you and the other members of the Committee, and to express my deep appreciation of the great honor which you did me.

Very sincerely yours,
W. D. COOLIDGE.

At a specially called meeting of the Edison Medal Committee held January 21, it was resolved ". . . . . with profound regret, to acquiesce in the decision of Dr. Coolidge, which nullifies the award."

Second Annual Welding Conference

More than 200 industrial men attended the second annual conference on welding held December 15-16-17, 1926 at LaFayette, Ind., under the auspices of the Engineering Extension Department of Purdue University. There were given several very interesting demonstrations in electric, thermit and oxy-acetylene welding and lectures by welding experts from all over the United States. Professor W. A. Knapp of Purdue University presided and introduced the speakers who were men of prominence in their profession. The attendance and interest shown in this second welding conference was most gratifying to the committee in charge.

American Engineering Council

THE ANNUAL MEETING, WASHINGTON, D. C.

The Annual Meeting of the American Engineering Council was held in Washington, D. C., at the Mayflower Hotel, January 13-15, 1927. The attendance of delegates and others interested was approximately one hundred. The various national, state and regional engineering societies constituting the membership of the Council were practically all represented by official delegates. President Dexter S. Kimball of Cornell University, presided.

President's Address

Opening the meeting of the Council, Dean Kimball put the question as to the reason for American Engineering Council,—"Why are we interesting ourselves in such subjects as politics, government, economics, and the great variety of topics that twenty-five years ago were entirely outside of the field of the engineer?" Reminiscing, he pointed to the fact that such things were not thought of in the engineering field until recently. A review of many of the reasons for this departure shows that it is due to the fact that the engineer has taken a prominent part in building "the most amazing civilization the world has ever seen,—with merely the resources of the North American Indian." Now it is time to record the experiences of the past and take cognizance of possibilities of our future development. "The engineer is in the van. Here is a problem worth solving and here is a group of engineers, and the problem is certainly worth their solving, and I do believe that the engineer if he puts his mind on the principle, and brings his mind to bear on it, using his methods which have been used to produce this tremendous volume of wealth, if he will bring his efforts to bear upon this field—the application of economics to production and then the application of economics to the broader distribution, we will do more than is is possible for any other group to do. We have a considerable ttart and background and the method and the ideals. It is part of a larger movement, one that we hope we may perform. I wish to say that other friends may come in on this work but that we as leaders and pioneers in this should take heart because I am sure we can make a real contribution, such as no other group has made since time immemorial."

Safety and Production

Of outstanding interest to all members of the Council in attendance was the progress being made in the Study on Safety and Production. An entire evening session was devoted to this subject following which the Assembly was satisfied that the report was progressing so satisfactorily its final acceptance could be left to the Executive Committee. The figures on this study show that the results will give a comprehensive cross section of American industry, since 18 of the basic industries of the country were well covered by 15 field engineers operating in the principal industrial centers of the country. The total number of companies represented in the survey will be practically 14,000, giving data for a total of 122,000 company years and involving a total in excess of 18,000,000 man years.

Indications are that the report will be able to clearly show that there is a great deal of room for improvement in safety work throughout American industry, although final conclusions will not be reached until the report is ready to be accepted. Its early completion is confidentially expected by the Committee having charge of the work, of which Mr. A. W. Berresford is Chairman.

Public Works Department

As the result of a year's study of the internal organization of the proposed department of public works, a special organization committee presented a complete report to the Assembly. The report was reviewed in detail as was also the revised congressional bills based upon the recommendations contained therein. Both were approved and plans were renewed for financing and pushing the public works movement to a successful conclusion. Gardner S. Williams, Chairman of Council's Committee on Public Works, intends to have the new bills introduced in Congress as soon as they have been edited.

Street and Highway Safety

As the result of a tender of the services of American Engineering Council to the National Conference on Street and Highway Safety, a Committee on Street Signs, Signals and Markings, headed by W. B. Powell, was created for the purpose of standardizing methods and devices of traffic control. The Committee started its work with two meetings at the last of which detailed plans were laid for a survey of about 250 cities which have a population of over fifty thousand, together with a few smaller sample cities to be picked out geographically. Engineers will be expected to assist in this work throughout the cities that are studied by collecting the necessary field data. Members of American Engineering Council were urged to assist in the assembling of data that would be satisfactory to the Committee throughout their districts. The development of general interest in the work of the Street and Highway Safety Council was urged so that a full understanding of the importance of this problem might be fostered through the engineering point of view.

Legislation

General support of several important pieces of legislation now before Congress were approved, such as the bill to employ engineers for consultation purposes in the Department of the Interior, the bill to increase and conserve the production of helium gas, and several bills relating to the Patent Office.

The continued interest of Council in patents work was further manifested by the adoption of a resolution presented by the Committee on Patent Office Procedure proposing to improve the classification and salaries of officials and examiners of the Patent Office.

Proposed State Engineering Councils

Pointing to the possibilities of more coherent engineering organizations throughout various states, American Engineering Council requested the Committee on Regional Activities to study into a more comprehensive state organization which might be developed by the creation of state councils.

Secretaries Conference

In connection with its effort to be of service to engineering organizations generally, it was decided to call another conference of secretaries of engineering organizations in Cleveland, Ohio, June 16 and 17, 1927. Mr. C. R. Sabin, Secretary of the Cleveland Engineering Society, was put in charge of this meeting.

All of the standing and special committees of Council were continued for next year, including representation on all of the Boards and Conferences in the work of which American Engineering Council participated last year.

Officers Elected

The officers elected at this Annual Meeting were Vice-Presidents A. W. Berresford, Detroit, Mich., and O. H. Koch, Dallas, Texas, for a two-year period; Treasurer H. E. Howe, Washington, D. C. (re-elected); and Executive-Secretary L. W. Wallace, Washington, D. C. (re-elected).

The hold-over officers are President Dexter S. Kimball, Ithaca, N. Y.; and Vice-Presidents Gardner S. Williams, Ann Arbor, Mich., and I. E. Moultrop, Boston, Mass.

The representatives of the A. I. E. E. present were A. W. Berresford, Detroit, Mich.; John H. Finney, Washington, D. C.; M. M. Fowler, Chicago, Ill.; H. M. Hobart, Schenectady, N. Y.; F. L. Hutchinson, New York, N. Y.; William McClellan, New York, N. Y.; Farley Osgood, New York, N. Y.; Charles F. Scott, New Haven, Conn.; Charles E. Skinner, East Pittsburgh, Pa.; Calvert Townley, New York, N. Y.; and A. G. Pierce, Cleveland, Ohio.

An announcement was made of the representatives who will constitute the Administrative Board for the year 1927, consisting of the President, the Vice-Presidents, the Treasurer and the representatives of the national societies and the regional districts. The delegration selected to represent the A. I. E. E. in addition to Vice-President A. W. Berresford, is composed of C. C. Chesney, John H. Finney, D. C. Jackson, Farley Osgood, Charles F. Scott and Charles E. Skinner.

The meeting closed with a dinner at the New Willard Hotel on Friday evening, January 14, which was attended by a large number of Washington engineers in addition to the members of the Council. Herbert Hoover, Secretary of Commerce, and Charles M. Schwab, President of the American Society of Mechanical Engineers, gave brief and exceedingly interesting addresses.

Radio Engineers Hold Successful Convention

On January 10-12, inclusive, the Institute of Radio Engineers held its Annual Convention at the Engineering Societies Building, 33 West 39th Street. The convention opened Monday morning with the presentation of the Liebmann Memorial Prize and the installation of officers for 1927, Doctor Ralph Bown of the American Telegraph and Telephone Company having been chosen to succeed Mr. Donald McNicol in the office of President.

Four extremely interesting papers were presented and discussed, among these being one by Doctor E. F. W. Alexanderson, consulting engineers of the General Electric Company, on the subject of television. There were also enjoyable and instructive inspection trips to the Electrical Testing Laboratories, the Dubilier Radio & Condenser Corporation's works, the plant of the Brandes Products Corporation, the Radio Corporation of America, Driver Harris Co., the WEAF National Broadcasting studio and control room and also Station WJZ. The convention closed with a banquet and entertainment at the Waldorf Astoria, the whole program being voted a great success by all who were fortunate in attending.

Safety Museum Awards Medals

On January 13th, Arthur Williams, president of the American Museum of Safety, tendered a luncheon to the presidents of the prize winning railroads, the trustees of the museum and other leaders of the safety movement. The luncheon was held at the Hotel Biltmore, and after a brief address, Judge Elbert H. Gary, as vice-president of the Museum presented the Harriman Medal, in gold, silver and bronze, to the presidents of the three railroads which have been most successful in the prevention of accidents to their employes and passengers during the year 1925. The medals are offered annually by Mrs. E. H. Harriman to stimulate interest in permanently organized activities for accident prevention for the employes as well as the passengers of the various railroads. John J. Esch, chairman of the Interstate Commerce Commission and a member of the Committee of Award, declared that "by the 1st of July of this year it is expected that 8000 miles of railroad will be supplied with some form of automatic train control to prevent collisions and from 6000 to 7000 locomotives will be so equipped." The medalists were W. A. McGonagle, president of the Duluth, Missabe and Northern Railway Company (silver medal), Charles W. Cox, Secretary-treasurer of the Green Bay and Western Lines, (bronze medal) and Carl Gray, president of the Union Pacific System (gold medal) for a record showing that not a single life had been lost during 1925, notwithstanding the fact that this company operates more than 53,000,000 locomotive miles and more than a billion passenger miles, due to railroad accident. Only five employes were killed in non-train accidents. Among the guests of honor were several prominent members of the Institute.

Central Station Design an Attractive Subject to New York Section

On the evening of Wednesday, January 19, 1927, the New York Section of the A. I. E. E. held a joint meeting with the Metropolitan Section of the A. S. M. E. in the Public Service Auditorium, Newark, N. J. The subject "Modern Central Station Design" proved very attractive as evidenced by an attendance of over 800. Four speakers covered both the mechanical and electrical sides of plant design as follows: E. B. Ricketts and R. H. Tapscott of the New York Edison Company on "The New East River Station" and R. J. S. Pigott and W. R. Smith of the Public Service Company on "The Kearney Station of the Public Service Company." The talks, which in general covered the bulk generation of power, dealt particularly with the engineering features underlying the general design and arrangement of the plants. All talks were generously illustrated with lantern slides. Chairman E. B. Meyer of the N. Y. Section A. I. E. E. presided over the presentation of the papers and Chairman Frost of the A. S. M. E. over the discussion. The meeting was preceded by a very successful "Get-to-gether Dinner" at the Robert Treat Hotel, attended by 420 members and guests.

New Electrical Safety Rules for Coal Mines

Safety rules for installing and using electrical equipment in coal mines, sponsored by the Bureau of Mines, Department of Commerce, and the American Mining Congress, have just been made public by the Bureau. In preparing the rules, five basic measures for safeguarding the use of electricity in mines have been followed, *viz.*: Removing the contributory causes of accidents or danger; removing from the vicinity of electrical apparatus all elements susceptible to the influence of electricity; complete control of electric current, or limiting the area of its activity by protective devices; using a large factor of safety in the selection, installation, and inspection of equipment, and the full control of the operation of electrically driven machines.

The new safety rules have been published in Technical Paper 402, copies of which may be obtained from the Bureau of Mines, Department of Commerce, Washington, D. C.

Specifications for Resident Lighting Equipment

A committee of the Association of Edison Illuminating Companies has prepared tentative specifications for guidance of central station members in selecting residence lighting equipment for sale to the public. This committee includes representatives of seven central station companies. It has enjoyed the cooperation of a committee of the Illuminating Engineering Society which has sponsored those portions of the specifications which have to do strictly with lighting qualities.

The specifications offer a method of appraising luminaires with respect to—(a) illuminating qualities; (b) construction and (c) appearance.

For purposes of the Association of Edison Illuminating

Companies a collection will be made of certain residence lighting equipment which attains to high rating under these specifications.

Copies of the specifications may be obtained from Electrical Testing Laboratories, 80th Street and East End Avenue, New York, N. Y.

University of Illinois Has Established Research Assistantships

Research Graduate Assistantships are being maintained by the Engineering Experiment Station of the University of Illinois. The research graduate assistants devote one-half time to engineering research and the remainder of their time to graduate study. The training they receive in engineering research and graduate study gives them excellent preparation for engineering teaching, for engineering research, and for the profession of engineering.

Additional information may be obtained by addressing the Director, Engineering Experiment Station, University of Illinois, Urbana, Ill.

PERSONAL MENTION

Thomas A. Fawell, previously of San Francisco, is now representing Kohlenite Products, Inc., of New York City and the Martindale Electric Company of Cleveland, Ohio.

C. H. Garcelon, formerly manager of the Small Motor Engineering Dept. of the East Pittsburgh Works, Westinghouse Electric & Mfg. Co. has been transferred to the East Springfield Works in like capacity.

John A. Cressey has been appointed Charge Engineer to the Shanghai Municipal Electricity Department and sailed for Shanghai on January 28th. Mr. Cressey was previously control engineer to the South Wales Power Company.

W. Nelson Smith, who, since March 1918, has been consulting electrical engineer to the Sydney E. Jenkins Co. of Vancouver, B. C. and the Winnipeg Electric Company, Winnipeg, Canada, has returned to the United States to make new business connections.

S. N. Clarkson, past chairman of the St. Louis Section of the Institute has been appointed assistant to the managing director of the National Electrical Manufacturers Association which was recently formed by the merging of the Electric Power Club, the Associated Manufacturers of Electrical Supplies and the Electrical Manufacturers' Council. Mr. Clarkson is well known in engineering circles, and brings to his new work the asset of a broad experience in the professional field.

Harry White, Manager of the Lamp Department of the American Electric Company, St. Joseph, Mo., has been awarded the first prize of $500 in the "Behind the Line" contest conducted by the Edison Lamp Works of the General Electric Company. The purpose of the contest was to introduce a new line of lamps, and more than 2000 sales managers, from all states in the union, participated. The presentation was made on January 17th.

Edward Caldwell has resigned from the presidency of the McGraw-Hill Book Company, Inc., and will retire from active business. Mr. Caldwell has been associated with the McGraw-Hill interests for thirty-six years. He was one of the organizers of the McGraw-Hill Book Company in 1909 and has been active in its management ever since. He will continue to serve the McGraw-Hill Corporation however, by remaining a member of their respective boards of directors.

Frederick M. Feiker, formerly chairman, Editorial Board, A. W. Shaw Company, Chicago, Vice President, the McGraw-Hill Company, New York; Assistant to the Secretary of Commerce, Washington, D. C., and latterly Operating Vice President of The Society for Electrical Development; has been appointed Managing director of The Associated Business Papers, Inc., New York City.

Addresses Wanted

A list of members whose mail has been returned by the postal authorities is given below, together with the addresses as they now appear on the Institute records. Any member knowing the present address of any of these members is requested to communicate with the Secretary at 33 West 39th St., New York.

All members are urged to notify the Institute Headquarters promptly of any changes in mailing or business address, thus relieving the member of needless annoyance and also assuring the prompt delivery of Institute mail, the accuracy of our mailing records, and the elimination of unnecessary expense for postage and clerical work.

1.—Norris H. Brown, 651 Marshall St., Milwaukee, Wisc.
2.—C. M. Burnham, Jr., 119 East 20th St., Chicago, Ill.
3.—J. A. Inch, 1651 Athol St., Regina, Sask., Canada.
4.—George I. James, Box 649, Murphysboro, Ill.
5.—Jorgen S. Jensen, Rm. 839, 72 W. Adams St., Chicago, Ill.
6.—R. D. McCormick, 162 Broad St., Weymouth, Mass.
7.—R. B. Merchant, 142 Khetwadi Main Rd., Bombay 4, India.
8.—Thos. E. Phelan, 45 E. 55th St., New York City.
9.—George O. Phelps, 89 Aspen Rd., Swampscott, Mass.
10.—Charles M. Ploetz, 523 4th Ave., Milwaukee, Wisc.
11.—Ernest Aug. Sykes, Club House, Cedars, Que., Canada.
12.—Charles P. Tymon, U. G. I. Contracting Co. P. O. Drawer 40, Syracuse, N. Y.

Obituary

Anson Wood Burchard, Associate of A. I. E. E., died suddenly January 24, 1927 at the home of Mortimer L. Schiff. Mr. Burchard since 1922 has been Vice-Chairman of the Board of the General Electric and prior to that time had been for many years a vice-president of the Company. He was Chairman of the Board of Directors of the International General Electric Company, and as such had the general direction of the export business of the company. In addition to this he was director of many public utility corporations. During the war he acted as assistant to Benedict Crowell, who was Director of Munitions.

Mr. Burchard was born on April 21, 1865 and was a graduate of the Stevens Institute of Technology in the class of 1885. When Charles A. Coffin was President of the General Electric Co. Mr. Burchard acted as Assistant to the President. Later he became a Vice-President, and on Mr. Coffin's retirement, Vice-Chairman of the Board and Chairman of the Executive Committee. Through his long association with the company, he had become very familiar with its business in all of its branches. He was an engineer by training and through many years experience, had acquired rare executive ability and financial understanding. His loyalty to the company and his pride in it, his devotion to his associates, and his wide interest in all good causes, made him universally respected and loved. His loss will be deeply felt.

In a statement issued by Mr. Clark H. Minor, President of the International General Electric Company he said:

"Mr. Burchard's death is a great shock to his associates and a host of friends in the International business world. His wise counsel and his splendid enthusiasm will always be missed. Throughout his long and successful career with the General Electric Company he maintained a deep interest in foreign markets. Mr. Burchard was influential in bringing about the organization of this Company, and he was an outstanding leader and executive in the business world. A man of wide experience, broad views, interested in the welfare of mankind, respected by all and dearly loved by his associates."

Past Section Meetings

Akron

Outdoor Substations, by Paul Simon, Delta Star Electric Co. Illustrated with motion pictures. December 17. Attendance 52.

Chicago

Electricity and Prosperity, by George Woodruff, The National Bank of the Republic. Response by W. L. Abbott, Past President, A. S. M. E. Dinner-Smoker. Among the prominent guests were Messrs. Bion J. Arnold, Past President, A. I. E. E.; B. G. Jamieson, Vice-President, 5th Geographical District, A. I. E. E.; M. M. Fowler, Manager, A. I. E. E., and the Chairmen and Secretaries of other engineering societies. Music and other entertainment were enjoyed. December 15. Attendance 401.

Cleveland

Transmission of Pictures by Wire, by R. D. Parker, American Tel. & Tel. Co. December 16. Attendance 250.

Columbus

Inspection trip to the Columbus Dispatch Printing Co. and the Adams Exchange of the Ohio Bell Telephone Co. September 25. Attendance 19.

Light and Illumination, by T. W. Rolph, Holophane Co., and

Problems of Underground High-Tension Transmission, by Professor A. F. Puchstein, Ohio State University. January 7. Attendance 30.

National and International Standardization, by C. E. Skinner, Westinghouse Elec. & Mfg. Co. December 3. Attendance 28.

Connecticut

Industrial Electric Heating—Its Economics and Applications, by R. M. Keeney, Connecticut Light and Power Co. December 14. Attendance 80.

Denver

Recent Development in the Steam Locomotive, by G. G. Jones, American Locomotive Co. Illustrated with slides. December 17. Attendance 31.

Detroit-Ann Arbor

Interconnections, by Alex Dow, Detroit Edison Co. October 26. Attendance 150.

Recent Advance in Electrical Communication, by L. S. O'Roark, Bell Telephone Laboratories, Inc. Illustrated with slides and moving pictures. December 14. Attendance 140.

Fort Wayne

Color Photography, by G. E. Mathews, Eastman Kodak Co. Illustrated with slides. Joint meeting with American Chemical Society. December 9. Attendance 80.

Indianapolis-Lafayette

Modern Development in Transporation, by W. C. Davis, General Electric Co. December 17. Attendance 33.

Ithaca

Get-Together with the Cornell E. E. Association. December 13. Attendance 80.

Kansas City

Changing Taps on Transformers under Load, by L. H. Hill, Westinghouse Elec. & Mfg. Co. Illustrated with slides. December 13. Attendance 26.

Lehigh Valley

Picnic and inspection trip to the Wallenpaupack Lake and Hydro Development of the Penna. Pr. & Lt. Co. Joint with Lehigh Valley Engineers' Club, and Iron and Steel Electrical Engineers. August 21. Attendance 250.

Light and Work, by W. H. Rademacher, Edison Lamp Works, and

The Funny Things That Cure People, by J. J. Walsh, Columbia University. The afternoon was devoted to inspection trip to Barrett-Haentjens (pump manufacturers) and Duplan Silk Corporation. December 11. Attendance 369.

Los Angeles

Ventilation and Cooling of Generators and Transformers, by Fred Garrison, General Electric Co., and C. J. Fechheimer, Westinghouse Elec. & Mfg. Co.; and

Operating Practises and Problems, by R. M. Peabody, Southern California Edison Co. Meeting preceded by a dinner. January 4. Attendance 68.

Louisville

Inspection trip to the City Exchange of the Southern Bell Telephone and Telegraph Co. Mr. M. A. Erskine, District Manager of this Company, gave a talk on the functioning of the local commercial organization and Mr. G. R. Armstrong, Louisville Hydroelectric Co., showed motion pictures and explained the construction of the dam across the Ohio River. December 14. Attendance 32.

Lynn

Proposed Development of the Tidal Power of the Bay of Fundy, by Dexter P. Cooper. Illustrated. December 15. Attendance 250.

The Shoe in Romance and History, by Major Cahill, United Shoe Machinery Co. Illustrated with slides. January 12. Attendance 98.

Minnesota

Dinner Dance. December 9. Attendance 60.

Niagara Frontier

The Resistor Electric Furnace and Some of Its Applications, by N. R. Stansel, General Elec. Co. December 17. Attendance 24.

Pittsburgh

Research, by W. R. Whitney, General Elec. Co. December 14. Attendance 305.

Pittsfield

Why Intelligent People Do Not Vote, by W. J. Millard, Field Secretary of the National Municipal League. December 16. Attendance 200.

Portland

Modern Street Lighting, by F. H. Murphy, Portland Elec. Pr. Co., and

Modern Highway Lighting, by G. N. Barker. November 18. Attendance 50.

The Chelan Development, by V. H. Greissen, The Washington Water Power Co. December 15. Attendance 110.

Providence

The Mercury Turbine, by L. A. Sheldon, General Electric Co. Joint meeting with Power Section of Providence Engg. Society. January 4. Attendance 120.

St. Louis

Radio Photography and Television, by E. F. W. Alexanderson, General Electric Co. December 15. Attendance 175.

San Francisco

Automatic Substations, by R. B. Kellogg, Pacific Gas and Electrip Co. November 19. Attendance 130.

Long-Distance Relief Project between Bay Area and Sacramento Valley, by E. M. Calderwood, Pacific Tel. & Tel. Co. Illustrated with slides. A dinner preceded the meeting, at which Professor H. H. Henline, who has recently been appointed Assistant National Secretary, A. I. E. E. gave a short talk. December 17. Attendance 245.

Saskatchewan

The Deisel Engine as a Prime Mover, by J. M. Bloomfield, Municipal Power Plant, and

Some By-Paths in Telephone Engineering, by W. H. Bentley, Saskatchewan Government Telephones. December 4. Attendance 23.

Schenectady

What Young Engineers Do in the Design Department. This was a symposium by H. E. Strang, E. P. Nelson, J. N. Alberti, K. C. Mobarry and B. O. Buckland.. The discussion was opened by E. W. Allen, Vice-President in Charge of Engineering of the General Electric Co. January 7. Attendance 150.

Seattle

The Geology of the Puget Sound Basin, by Dean Henry Landes, University of Washington. November 16. Attendance 84.

Sharon

Transmission of Pictures by Wire, by Dirk Schregardus, Bell Telephone Laboratories. January 4. Attendance 94.

Spokane

Chelan Development of the Washington Water Power Company. This was a symposium by E. H. Collins, L. J. Pospisal and Richard McKay. December 17. Attendance 100.

Springfield

Electric Industrial Heating, by C. W. Babcock, Westinghouse Electric & Mfg. Co. December 20. Attendance 27.

Syracuse

Arc Welding Steel Structures, by A. M. Candy, Westinghouse Electric & Mfg. Co. December 13. Attendance 208.

Development and Manufacture of Transformers, by C. C. Chesney, National President, A. I. E. E. The meeting was preceded by a dinner. A motion picture on the manufacture of transformers was shown. January 3. Attendance 165.

Toronto

The Physical Characteristics of the Human Voice, by Prof. E. F. Burton, Toronto University. Joint meeting with Institute of Radio Engineers. December 8. Attendance 65.

Utah

Automatic Hydroelectric Stations, by R. E. Pierce and G. R. Olson, Utah Power and Light Co. Motion pictures, entitled "Automatic Substations for Mining and Industrial Service," "Distributor Type Supervisory System," and "Electrical Travelogue." December 21. Attendance 30.

Vancouver

Electric Boilers, by Douglas Robertson. December 7. Attendance 52.

Washington, D. C.

The Conowingo Hydroelectric Development, by W. C. L. Eglin, Philadelphia Electric Co. Illustrated with slides. Joint meeting with A. S. M. E. and the American Society of Engineers. A dinner preceded the meeting. December 14. Attendance 425.

Some Problems of Long Distance Telephony, by H. S. Osborne, American Telephone and Telegraph Co. Illustrated with slides and moving pictures. Mr. S. Norstrum, Swedish Telegraph Administration, spoke briefly lauding American people for the stage which telephony has reached in this county. January 11. Attendance 208.

A. I. E. E. Student Activities

The electrical engineering students in the colleges today constitute the group from which will be built the foundation of the Institute of the future. In recognition of this fact, the Board of Directors of the Institute, many years ago, authorized the establishment of Student Branches composed of electrical engineering students in the various colleges, for the purpose of providing an instrumentality for the development of the latent ability of students in carrying on organization work by actual participation in meetings and other activities.

During the past year the Directors have instituted another step toward the further development of Student activities by authorizing the appointment of a Counselor in each Branch, who is in each instance a member of the faculty in which the Branch is located and also a member of the Institute.

A Committee on Student Activities has also been authorized in each of the Geographical Districts, composed of the Counselors within the District together with the Vice-President and Secretary of the District. The principal function of these District committees will be to coordinate Student activities in their localities.

At a recent meeting of the Publication Committee of the Institute, it was decided to inaugurate a separate department in the monthly JOURNAL, to be published under the above heading and in which will be included brief references to the activities of the Student Branches, the Counselors, the District committees and any other matters of interest within the field indicated. It is believed that this department will result in increased interest in, and activity by, the Students, and it is hoped that it will be possible to include in this department of the JOURNAL from time to time, some of the worthier papers presented by the Students, at various meetings, as for example, the prize-winning Student papers in the various Districts.

STUDENT CONVENTION IN CALIFORNIA

As part of a plan to secure closer cooperation between the San Francisco Section and the neighboring Branches of the Institute, arrangements were made for a Student Convention at Stanford University on the afternoon of January 14th, and for a dinner at the University and evening technical meeting at the Harris J. Ryan High Voltage Laboratory, both to be attended by Branch and Section members.

Members of all Branches within a radius of about 500 miles were invited to attend the Convention, and a considerable number from the University of California, University of Santa Clara, and Stanford University Branches were present, the total attendance at the afternoon meeting being about 105. Of this number about 95 were enrolled Students.

Chairman Pering of the Stanford Branch, who was also Chairman of the Convention Committee, presided, and the following program was presented:

Some Practical Aspects of Engineering.

P. M. Downing, Vice President, District No. 8, A. I. E. E. This address included some of Mr. Downing's personal experiences in getting started on his engineering career.

Protection of Underground Structures from Corrosion.

Francis K. Scott and Nicholas Fossati, University of California Branch.

Ryan Laboratory Opens Untouched Fields for Electrical Investigation.

Joseph T. Lusignan, Jr., Stanford Branch. This paper includes a complete description of the new laboratory and equipment and a discussion of the methods of operation.

The Future of the Electrical Industry on the Pacific Coast.

Professor Harris J. Ryan, Head of Department of Electrical Engineering, Stanford University.

BRANCH MEETINGS

Municipal University of Akron

Outdoor Substations, by Mr. Simons, Delta Star Co. December 17. Attendance 15.

Alabama Polytechnic Institute

The Selection of an Apprenticeship Course, by Prof. W. W. Hill, Counselor of the Branch. January 5. Attendance 33.

The History of the Telephone Business, by Kendal Weisiger, Southern Bell Telephone Co. Joint meeting with A. S. M. E. January 12. Attendance 43.

Armour Institute of Technology

Great Men of Electricity, by Edwin H. Madden and George E. Coole, students. December 16. Attendance 50.

Carrier Wave Telephony, by Alfred E. Petrie, student. January 5. Attendance 35.

California Institute of Technology

Oscillograms of Conditions Occurring in Fuse Testing, by T. M Blakeslee, student, U. S. C. Illustrated with slides;

The Problems of Dam Sites, by A. M. Walker, student, U. S. C.;

Responsibility of the Engineer, by E. Hendry, student, U. S. C.;

The History and Latest Development of the Vacuum Switch, by F. Lindvall, student, C. I. T., and

Experimentation with Lightning Involving the Problems of Oil Tank Protection, by C. D. Hayward, student, C. I. T. Joint meeting with Los Angeles Section and University of Southern California Branch, preceded by a dinner at the C. I. T. cafeteria. Immediately following the meeting an inspection was made of the electrical engineering laboratories of the C. I. T.; also the 1,000,000-volt laboratory where the remainder of the program was carried out in practical demonstrations. December 7. Attendance 200.

Carnegie Institute of Technology

Mine Electrification, by Graham Bright. Consulting Engineer. December 15. Attendance 22.

Case School of Applied Science

Get-Together and Smoker. Short talks were given by members of the faculty. December 7. Attendance 52.

Clemson Agricultural College

Business Meeting. The following officers were elected: Chairman, L. R. Miller; Vice-Chairman, R. C. Dill; Secretary-Treasurer, J. U. Wilson. October 12. Attendance 13.

Electrical Suburban Service on the Illinois Central Railroad, by R. M. Marshall;

White Way Street Lighting for Small Cities, by H. L. Baldwin, and

Current Events, by R. H. Mitchell. November 11. Attendance 26.

Replacing Commutator Bars, by C. B. Dowling, and

Air Blast Transformers, by W. J. Googe. December 2. Attendance 20.

University of Colorado

The Sugar Industry in Porto Rico, by Mr. Price, a recent graduate of the University. Joint meeting with A. S. M. E. December 8. Attendance 61.

Cooper Union

The Cathode Ray Oscillograph, by F. J. Rasmussen, Bell Telephone Laboratories. December 17. Attendance 60.

Inspection trip to I. R. T. main generating plant at 59th Street and 11th Avenue. December 12. Attendance 30.

University of Denver

What is Expected of a College Graduate by Large Electric Companies, by Bert Schuler, Westinghouse Elec. & Mfg. Co. A motion picture entitled "The Consolation Club," was also shown. December 15. Attendance 25.

Iowa State College

Business Meeting. December 14. Attendance 19.

Kansas State College

New Steel-Lined Mercury Arc Rectifier, by W. B. Anderson, Westinghouse Elec. & Mfg. Co. Illustrated.

The Westinghouse Graduate Student Course. January 5. Attendance 150.

University of Kansas

Things Other Professors May Teach Electrical Engineers, by Chancellor E. H. Lindley. Talks were also given by the following students: Messrs. L. L. Parker, J. P. Clifton, R. M. Alspaugh and H. R. Hilkey. Annual Banquet. December 9. Attendance 142.

Louisiana State University

Superpower as an Aid to Progress, by K. J. Ozment, Chairman of the Branch, Dr. W. H. Gates also gave a talk on his experiences while employed by the General Electric Co. December 2. Attendance 27.

Massachusetts Institute of Technology

Substation Maintenance, by S. W. Marshall, Jr., student. December 14. Attendance 35.

University of Maine

Signal Corps and Their Work, by Col. Black;

American Radio Relay League, by Capt. Stanion;

The Bell Telephone Laboratories, by Prof. Crabtree, and

Recent Visits to Leading Electrical Industries, by Dean Cloke. December 10. Attendance 33.

Marquette University

Effect of Wave Frequency Cut-Off on Voice Transmission, by H. R. Huntley, Wisconsin Telephone Co. Illustrated. This was followed by a demonstration of the effect of frequency cut-off, using condensers and amplifying apparatus, on voice, music and various other types of sound. December 9. Attendance 35.

University of Michigan

Automatic Telephone, by Maurice H. Nelson. Demonstrated by a model 1000-line automatic telephone exchange. October 20. Attendance 77.

Electric Transmission of Power, by Joseph Slepian, Westinghouse Elec. & Mfg. Co. In the afternoon a demonstration was given of the short-circuit test board of the Commonwealth Power Corp. The Branch was the guest of the Detroit-Ann Arbor Section at this meeting. November 9. Attendance 250.

Choosing a Job, by J. T. Sheafor, Michigan Bell Telephone Co. A motion picture, entitled "The Wizardy of Wireless," was also shown. November 26. Attendance 70.

Montana State College

The G. E. Graduate Course, by B. L. Snoddy, General Electric Co. December 2. Attendance 185.

Circular and Hyperbolic Functions, by Wm. E. Pakala. December 9. Attendance 189.

University of Nebraska

Rural Electric Service, by W. R. McDeachin, Nebraska Gas and Electric Co. January 7. Attendance 30.

College of Engineering of the Newark Technical School

The Construction of the Holland Tunnel, by Mr. Baridale, Chief Engineer in Charge of the Tunnel. Joint meeting with other engineering societies. December 15. Attendance 78.

University of New Hampshire

Post-Graduate Work in the Westinghouse Company, by R. F. Carey. November 29. Attendance 62.

Multiple-Unit Cars, by R. W. Folsom, student, and

Gasoline-Electric Motor Busses, by S. A. Lewis, student. December 6. Attendance 39.

Electric Refrigeration, by R. T. Lord, student, and

A Walk Through a Power Plant, by E. A. Goodwin, student. December 13. Attendance 40.

College of the City of New York

Inspection trip to the Manual Section of the Audubon Telephone Exchange. November 10. Attendance 18.

Inspection trip to the Automatic Section of the Edgecombe Telephone Exchange. November 17. Attendance 18.

Inspection trip to the Tandem and Long Distance Telephone Exchange of the A. T. & T. Co. November 24. Attendance 15.

Inspection trip to the Edison Lamp Works of the General Electric Co., Harrison, N. J. November 26. Attendance 13.

Business Meeting. December 9. Attendance 19.

New York University

Tungar Rectifiers by Mr. Greenstein, student. December 3. Attendance 17.

Radio Transmission, by Mr. Alexander Senauke, Popular Science Institute of Standards. December 10. Attendance 26.

University of North Carolina

Illumination, by Professor J. E. Lear. December 2. Attendance 33.

University of North Dakota

Theory and Construction of the Induction Motor, by Herbert Tellman and

Fire Protection in Hydro-Electric Plants, by Nels Anderson. November 29. Attendance 11.

Visible Radio Waves, by Heinrick Polsfut, and

Observations Made While Working with the Bell Telephone Company, by James Peterson. December 13. Attendance 13.

Northeastern University

New Landmarks in Electrical Communication, by R. B. Meader, Bell Telephone Laboratories. Illustrated with motion pictures. December 7. Attendance 82.

Ohio Northern University

Moving picture, entitled "Power Transformers," was shown. December 16. Attendance 100.

Fundamental Principles, by Prof. Berger, and

The Progress of Technical Societies in the Last Five Years, by Prof. Campbell. January 6. Attendance 38.

Ohio State University

Business Meeting. A short talk was given by Prof. Caldwell, Counselor of the Branch, on the benefits of the A. I. E. E. to the electrical engineer while he is in college and after graduation. October 15. Attendance 60.

Manufacture of Carbons from Raw-Materials to Finished Products, by A. M. Lloyd, National Carbon Co. Accompanied by motion pictures. October 22. Attendance 75.

The Automatic Telephone, by Prof. W. L. Everitt. A short talk was also given by Prof. Alva Smith. November 4. Attendance 100.

Mine Haulage Motors and Coal Cutting Motors: Their Design and Application, by R. R. Dunlap, Jeffery Manufacturing Co. November 12. Attendance 80.

The Elimination of Waste through Simplification and Standardization, by C. E. Skinner, Westinghouse Elec. & Mfg. Co. December 3. Attendance 70.

The Human Element of Lighting Practise, by G. H. Stickney, Edison Lamp Works of G. E. Co. December 10. Attendance 94.

University of Oklahoma

Advantages of Enrolment in the A. I. E. E. to Students, by Prof. F. G. Tappan, and

Summer Experiences, by Ed. Durbeck, Ralph Tyler and Otis Stevens, students. A motion picture, entitled "A 60,000 Kw. Turbo-Alternator," was also shown. October 28. Attendance 28.

A review of the Kearny Steam Station of the Public Service Company, by Elmer Dixon;

A Description of the Avon Station Owned by the Cleveland Electric Illuminating Co., by Earl Hassler;

A Review of the Wallenpaupach Hydro-Electric Plant and Transmission Lines, by Chas. Musson, and

The Automatic Hydro-Electric Plant at Potsdam, New York, by T. J. Alworth. November 18. Attendance 21.

Motion picture, entitled "The Sound Transmitter," was shown. December 16. Attendance 19.

Pennsylvania State College

Typical Public Utility Organization, by W. R. Wendell;

Holding Companies, by G. C. Huggler;

Banking Methods and Affiliations, by L. K. Werkheiser, and

More Light and More Power Too, by E. H. Basehore. December 14. Attendance 25.

University of Pittsburgh

A Short Biography of Steinmetz, by Paul E. Lagatola, student;

Advancement of Electrical Science, by Norman Orr, student, and

Elimination of Radio Interference, by L. B. Biebel, student. December 3. Attendance 27.

The Relation of Power Development to Social Progress, by G. M. Gadsby, West Penn Power Co. Joint meeting with other engineering societies. December 10. Attendance 125.

The Manufacture of Natural Gasoline, by George Burrell, Standard Oil Co. Joint meeting. December 17. Attendance 130.

Purdue University

Recent Developments in Signal Communication, by M. B. Long, Bell Telephone Laboratories, Inc. Slides and a motion picture, entitled "The Magic of Communication," were used to illustrate the lecture. January 11. Attendance 85.

Rensselaer Polytechnic Institute

A. C. Synchronous Machines, by C. M. Cogan, General Electric Co. Illustrated with slides and motion pictures. December 14. Attendance 90.

Rutgers University

The Highway Problems of New Jersey, by Major W. G. Sloan Joint meeting with A. S. C. E. December 13. Attendance 75.

The Engineer after Graduation, by E. B. Meyer, Public Service Production Co. Illustrated with slides. January 10. Attendance 73.

University of Santa Clara

Business Meeting. December 7. Attendance 22.

South Dakota State School of Mines

The Northern Lights, by Elmer Stonefelt;

Matters of General Scientific Interest, by Dr. C. C. O'Harra, and

The Theory and Experimental Results of Static and Electrical Interference in the Heterodyne Receivers, by Frank Burris. November 3. Attendance 27.

Motion pictures, entitled "The Audion" and "Through the Switchboard," were shown. December 17. Attendance 425.

Business Meeting. January 5. Attendance 13.

University of Southern California

See December 7 meeting of California Institute of Technology.

Stanford University

Transmission of Photographs over Telephone Lines, by H. G. Tasker, Pacific Tel. & Tel. Co. Illustrated. October 27. Attendance 29.

Business Meeting. Plans for the Student Convention and joint meeting with the San Francisco Convention to be held on January 14 were discussed. November 23. Attendance 14.

Business Meeting. Mr. T. H. Morgan was nominated Branch Counselor. December 9. Attendance 16.

Swarthmore College

The Engineer after Graduation, by Herbert Spackman, Bethlehem Steel Co. October 14. Attendance 30.

The Production and Uses of Rubber, by Mr. Wohr, Manhattan Rubber Co. Illustrated. The following officers were elected: Chairman, Edward Fairbanks; Secretary, Walter Denkhaus. December 9. Attendance 25.

Syracuse University

Hydraulic Power in State of Washington, by M. L. Ernst. October 27. Attendance 25.

Hydraulic Power in South America, by M. S. Ewing. November 3. Attendance 24.

Possibilities of Hydraulic Power in Europe, by J. C. Frink. November 10. Attendance 22.

Hydraulic Power Development in Europe, by G. E. Garnhart. November 17. Attendance 22.

Development of Power on St. Lawrence River, by J. V. T. Grove. December 1. Attendance 22.

Power Policy of the Federal Government, by T. P. Hall. December 8. Attendance 22.

University of Texas

Business Meeting. September 30. Attendance 19.

The Advantages of the Student Branch of the A. I. E. E., by Prof. J. A. Correl, and

Facts About the Trinidad Plant of the Texas Power and Light Company, by R. E. Shelby. October 13. Attendance 24.

Foundation and Object of Nela Park, by Prof. J. M. Bryant, and

Experiences at Nela Park School of Lighting, by J. W. Knudson. October 27. Attendance 26.

Experiences in the Westinghouse Factories at East Pittsburgh, by Carl Eckhardt. November 23. Attendance 16.

University of Utah

Business Meeting. The following officers were elected; Chairman, J. Irvin Farrell; Vice-Chairman, H. Eugene Larson: Secretary, Morris L. Hoag. October 7. Attendance 18.

Motion picture, entitled "King of the Rails," was shown. Meeting of The Engineering Society of Utah, the program being furnished by the A. I. E. E. Branch. November 2. Attendance 75.

Washington University

Developments in Radio Engineering, by Dr. E. F. W. Alexanderson, The Radio Corporation of America. Dr. Alexanderson also spoke of his experience with young engineers. December 14. Attendance 50.

Inspection trip to the Scullin Steel Company Plant. December 20. Attendance 20.

University of Wisconsin

Get-Together. October 22. Attendance 40.

Business Meeting. Educational motion picture films were shown. November 9. Attendance 50.

Rural Electrification and Its Problems, by G. C. Neff, Wisconsin Power and Light Co. December 14. Attendance 30.

Engineering Societies Library

The library is a cooperative activity of the American Institute of Electrical Engineers, the American Society of Civil Engineers, the American Institute of Mining and Metallurgical Engineers and the American Society of Mechanical Engineers. It is adminstered for these Founder Societies by the United Engineering Society, as a public reference library of engineering and the allied sciences. It contains 150,000 volumes and pamphlets and receives currently most of the important periodicals in its field. It is housed in the Engineering Societies Building, 29 West Thirty-ninth St., New York.

In order to place the resources of the Library at the disposal of those unable to visit it in person, the Library is prepared to furnish lists of references to engineering subjects, copies or translations of articles, and similar assistance. Charges sufficient to cover the cost of this work are made.

The Library maintains a collection of modern technical books which may be rented by members residing in North America. A rental of five cents a day, plus transportation, is charged.

The Director of the Library will gladly give information concerning charges for the various kinds of service to those interested. In asking for information, letters should be made as definite as possible, so that the investigator may understand clearly what is desired.

The library is open from 9 a. m. to 10 p. m. on all week days except holidays throughout the year except during July and August when the hours are 9 a. m. to 5 p. m.

BOOK NOTICES DECEMBER 1-31, 1926

Unless otherwise specified, books in this list have been presented by the publishers. The Society does not assume responsibility for any statement made; these are taken from the preface or the text of the book.

All books listed may be consulted in the Engineering Societies Library.

ADMINISTRATION OF VOCATIONAL EDUCATION OF LESS THAN COLLEGE GRADE.

By J. G. Wright and Charles R. Allen, N. Y., John Wiley & Sons, 1926. 436 pp., graphs, forms, tables, 8 x 5 in., cloth. $3.00.

The work of two men with unusual experience in the administration and analysis of vocational education, this book is a careful, detailed discussion of the responsibilities of the administrator of vocational education and of the ways in which school and work may be combined to supplement each other.

ANLEITUNG ZU GENAUEN TECHNISCHEN TEMPERATURMESSUNGEN.

By Osc. Knoblauch and K. Hencky. 2nd edition. Mün. u. Ber., R. Oldenbourg, 1926. 174 pp., illus., diagrs., 9 x 6 in., paper. 9.-mk.

While physicists and engineers can obtain a knowledge of the laws underlying the various ways of measuring temperatures and of the methods used from textbooks of physics and practical handbooks, they do not find in these, however, advice on certain topics of great practical importance, such as the proper installation of measuring instruments in machines and furnaces, so that sources of error will be minimized. It is with this question that the present book deals. It discusses the possible sources of error in the various industrial applications of thermometers and pyrometers, their probable effect on the readings and the ways in which they can be eliminated.

ART DE L' INGENIEUR ET METALLURGIE

Compiled by L. Descroix. (Extrait du vol. 5, Tables Annuelles de Constantes et Données Numériques). Paris, Gauthier-Villars et cie.; Chicago, University of Chicago Press, 1926. 251 pp., tables, 11 x 9 in., paper. With 25% discount allowed to Society members, price is 78.75 fr., unb., or 94,50 fr., bound. Apply to M. Charles Marie, General Sec'y, 9 Rue de Bagneux, Paris, VI^e.

The annual tables of numerical data and constants summarize those that have appeared in scientific and technical publications throughout the world and present them in convenient form for reference, with citations of the sources from which they are taken. The volume at hand, extracted from volume 5 of the tables, contains the data of importance to engineers and metallurgists which were published in the years 1917-1922, inclusive. It makes available much recent information on the physical and chemical properties of structural materials, on fuels and metals, and on electrical and magnetic constants. Similar volumes are available for the years from 1912 to 1916. The series is a complement to the recently published "International Critical Tables." It is published under the patronage of the International Research Council.

BROADCAST RECEPTION IN THEORY AND PRACTICE.

By J. Laurence Pritchard. Lond., Chapman & Hall, 1926. 259 pp., illus., diagrs., tables, 9 x 6 in., cloth. 8/6.

A handbook for the amateur maker of radio apparatus which is intended as an intermediate stage between books on the construction of receiving sets and those that deal exclusively with theory. It assumes a general knowledge of the use of tools and of elementary electricity, and attempts, on this basis, to explain the principles of wireless reception so that the experimenter may build the set he requires, and alter and adjust with knowledge.

CORK. A Civic Survey.

Prepared by the Cork Town Planning Association. Liverpool, University Press of Liverpool; Lond., Hodder & Stoughton, 1926. 30 pp., plates, maps, 13 x 10 in., paper. 10s.

As a preliminary step toward the preparation of a plan for the city of Cork, the Cork Town Planning Association has published this attractive booklet describing existing conditions in that city. The survey is designed to direct attention to the various factors that must be considered while making a plan, including such topics as physical features, history, regional considerations, industries, population, health, housing, natural zoning, communications, markets, public buildings, streets and open spaces. A brief text and many maps set forth Cork of today clearly.

DETAILED REPORT ON MERCER, MONROE AND SUMMERS COUNTIES.

By David B. Reger. Morgantown, W. Va., West Virginia Geological Survey, 1925. 963 pp., illus., with separate case of maps. $3.50.

Extra copies of Geologic map of Monroe County, $1.00, and Topographic map, 50 cents. Extra copies of Geologic and Topographic maps of each of the other counties, 50 cents each. Address West Virginia Geological Survey, P. O. Box 848, Morgantown, W. Va.

ELEMENTS OF ASTRONOMY.

By Edward Arthur Fath. N. Y., McGraw-Hill Book Co., 1926. 307 pp., illus., tables, 9 x 6 in., cloth. $3.00.

Intended primarily for use by college freshmen with no mathematics except elementary algebra and plane geometry, this book aims to present the necessary physical concepts so that they will obtain the main facts of the subject and have also an elementary understanding of the principles and methods involved in modern astronomical investigation.

ELEMENTARY MECHANISM.

By A. T. Woods and A. W. Stahl; revised and rewritten by Philip K. Slaymaker. N. Y., D. Van Nostrand & Co., 1926. 250 pp., illus., diagrs., tables, 9 x 6 in., cloth. $3.00.

The purpose of the original authors of this work was to prepare a textbook on kinematics, suitable in size to the requirements

of students of engineering. This was accomplished by avoiding purely theoretical discussions and confining the text to a clear description of those mechanical movements that may be of practical use and the discussion of the principles that underlay them.

After many years of popularity, Professor Slaymaker has prepared this new edition. In it much of the original text has been rewritten, new matter has been added, modern applications have been introduced and the book brought up to date generally.

Graphic Charts in Business.

By Allan C. Haskell. 2d edition. N. Y., Codex Book Co., 1926. 413 pp., diagrs., charts, 8 x 6 in., cloth. $4.00.

A practical book that omits mathematical discussion and goes directly to the question of the ways in which the business man may use graphic charts. The various types of charts are described, and the things that each will and will not show are explained. Definite instructions for the construction of each type are given. The use of charts in the various departments of a business are set forth and illustrated by reproductions of many charts.

Trains, Tracks and Travel.

By T. W. Van Metre. N. Y., Simmons-Boardman Publ. Co., 1926. 236 pp., illus., 10 x 7 in., cloth. $3.50.

Professor Van Metre apparently has set himself the task of answering every one of the questions that can occur to curious travelers or the average boy. Step by step he describes the track, locomotives, passenger and freight cars, stations, terminals and train operation. The language is clear and simple, no detail seems to be omitted and there is an abundance of illustrations. The book is a model of description of a technical subject to an untechnical audience.

Traffic Management.

By G. Floyd Wilson. N. Y., D. Appleton & Co., 1926. 453 pp., graphs, forms, 9 x 6 in., cloth. $3.50.

Traffic management, as used here, refers to the management of traffic and transportation affairs by men employed by industrial concerns and other business enterprises; the buyers of transportation, as distinguished from the sellers. Dr. Wilson discusses the function and services of industrial traffic organizations, presents the plans of organization and administration of industrial and commercial traffic departments of various types, and certain questions in the broader field of traffic management which require attention.

Text-Book of Rand Metallurgical Practice.

Vol. 1. 3rd edition, revised, by [H. A. White]. Lond., Charles Griffin & Co., 1926. 564 pp., illus., diagrs., tables, 9 x 6 in., cloth. 30s.

This work was written by a group of men actively engaged in metallurgical practice upon the Witwatersrand, each of whom treated the special branch of the subject upon the experience gained in the course of his daily duties. It aims to describe mechanical and chemical metallurgical practice on the Rand from the delivery of the ore at the shaft head to the disposal of the classified products.

Volume one has been unprocurable for some years, it is said. It is now reissued, with supplements to each chapter, by H. A. White, which bring the account of each subject up to date.

Subject Index of the Transactions of the Optical Society, v. 1-25.

By A. F. C. Pollard. Cambridge, University Press, 1926. 89 pp., 9 x 6 in., paper. Price not given.

Decimal Bibliographical Classification of the Institut International de Bibliographie.

Translated by A. F. C. Pollard. Cambridge, University Press, 1926. 109 pp., 9 x 6 in., cloth. Price not given. (Gift of Optical Society, Imperial College of Science and Technology, South Kensington).

The first of these books is an index to the contents of the first twenty-five volumes of the Transactions of the Society, classified by subject according to the Decimal Bibliographical Classification of the Institut International de Bibliographie. The index is printed on one side of thin paper in order that the notices may be cut and pasted to standard 75 and 125 mm. cards. Notices are provided for each subject treated in a paper. The form of entry is that used by the best catalogers and the printing is good. The index may serve as a model to other workers.

The second book is primarily a guide to the first. It is a translation of part of the classification tables of the Institut, hitherto available only in the French language. Professor Pollard has translated the description of the principles underlying the classification, the rules adopted for it, the explanation of its use, part of the principal tables, and the auxiliary tables that give such range and flexibility to the system.

Although the translation has been made with special reference to the needs of those interested in optics, it has much of value for workers in other fields.

Practical Colloid Chemistry.

By Wolfgang Ostwald and others. N. Y., E. P. Dutton & Co., 1926. 191 pp., illus., tables, 8 x 5 in., cloth. $2.25.

A manual of experimental colloid chemistry which attempts to present systematically its phenomena. Intended as a guide in the laboratory. The translation has been made from the fourth German edition.

Patents; What a Business Executive Should Know about Patents.

By Roger Sherman Hoar. N. Y., Ronald Press Co., 1926. 232 pp., 9 x 6 in., cloth. $4.50.

The author is at the head of the patent department of a large manufacturing concern. He attempts in this book to present those portions of the law and practice of patents which are of direct interest to executives, in language devoid of legal terminology. The subject is patent tactics rather than patent law.

Les Ondes Electriques Courtes.

By René Mesny. Paris, Les Presses Universitaires de France, 1927. (Recueil des Conférences-Rapports de documentation sur la physique, v. 12, 2e serie). 163 pp., diagrs., 10 x 6 in., boards. 30 fr.

Under the auspices of a number of important French scientific institutions a series of public conferences has been established for giving critical, detailed expositions of modern work upon important questions of physics and its applications. The conferences are intended to give workers in pure and applied science a knowledge of recent developments in each field of research.

The present monograph gives an account of short electric waves. It discusses their propagation, emission and reception, and gives the results of the research that has been carried out upon these.

New Building Estimators' Handbook.

By William Arthur. 14th edition. N. Y., Scientific Book Corporation, 1926. 1018 pp., illus., tables, 7 x 5 in., fabrikoid. $6.00.

A new edition of a useful handbook on costs of building. It contains data on the cost of materials and labor covering the various usual work met with in building and municipal work. The new edition has been revised and some new material has been added.

Modern Telpherage and Ropeways.

By Herbert Blyth. N. Y., Van Nostrand Co., 1926. 156 pp., illus., diagrs., 10 x 7 in., cloth. $7.00.

The author has long been associated with the development of telpherage systems in Great Britain. He here describes in a practical manner, from the point of view of the engineer, the considerations that underlie the application of telpherage and ropeways to conveying and the systems in use. A number of installations are included which show how specific problems have been solved.

Jahrbuch der Deutschen Gesellschaft fur Bauingenieurwesen. 1926.

Berlin, V. D. I. Verlag, 1926. 229 pp., illus., port., map, tables, 8 x 6 in., paper. 10.-r. m.

The second yearbook of the German Society for Structural Engineering is designed to present the usual information about it and also to supply certain data frequently wanted by engineers. Interesting papers are included on developments during the year in concrete and reinforced concrete, on underground structures in cities and on flying fields. The most valuable material, however, is in the summaries. These comprise, among others, statistics of the large hydraulic power plants of Germany, a list of the important engineering constructions of the year, a catalog of the dissertations presented to German universities during the years 1918-1926 for the degree of Doctor of Engineering, and a bibliography of monographs for structural engineers.

Engineering Societies Employment Service

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MEN AVAILABLE.—Brief announcements will be published without charge but will not be repeated except upon requests received after an interval of one month. Names and records will remain in the active files of the bureau for a period of three months and are renewable upon request. Notices for this Department should be addressed to ***EMPLOYMENT SERVICE, 33 West 39th Street, New York City,*** *and should be received prior to the 15th day of the month.*

OPPORTUNITIES.—A Bulletin of engineering positions available is published weekly and is available to members of the Societies concerned at a subscription rate of $3 per quarter, or $10 per annum, payable in advance. Positions not filled promptly as a result of publication in the Bulletin may be announced herein, as formerly.

VOLUNTARY CONTRIBUTIONS.—Members obtaining positions through the medium of this service are invited to cooperate with the Societies in the financing of the work by nominal contributions made within thirty days after placement, on the basis of $10 for all positions paying a salary of $2000 or less per annum; $10 plus one per cent of all amounts in excess of $2000 per annum; temporary positions (of one month or less) three per cent of total salary received. The income contributed by the members, together with the finances appropriated by the four societies named above, will it is hoped, be sufficient not only to maintain, but to increase and extend the service.

REPLIES TO ANNOUNCEMENTS.—Replies to announcements published herein or in the Bulletin, should be addressed to the key number indicated in each case, with a two cent stamp attached for reforwarding, and forwarded to the Employment Service as above. Replies received by the bureau after the positions to which they refer have been filled will not be forwarded.

POSITIONS OPEN

ENGINEER, experienced, a graduate of an American technical college, and with some experience in the design of A-C. or D-C. motors in the moderate sizes. Apply by letter. Location, Pennsylvania. X-1130.

GRADUATE, young, electrical or electrochemical engineer, for manufacturer of storage batteries and radio appliances. Must be interested in battery production and development. Apply by letter. Location, Wisconsin. X-1154-R-124-C

ELECTRICAL ENGINEERS, 3, technical graduates who have had from two to four years' practical experience, preferably in connection with design work with companies manufacturing electrical apparatus. Able men who have had experience in laboratory or application work provided the class of work that they have been handling is of such a nature as to make their experience valuable to them in this line of work also considered. Should have thorough grounding in mathematics, physics, and the fundamentals of electrical engineering. Location, Pennsylvania. X-1722.

ELECTRICAL ENGINEER, with several years' active experience in the design and application of universal motors. Apply by letter stating fully experience, education, age, and whether or not employed at present time. Location, New England. X-1304-C.

MEN AVAILABLE

ELECTRICAL ENGINEER, 35, married, eighteen years' experience, light, power, H. T., L. T., railways, power companies, as electrician, draftsman, chief electrician, chief electrical engineer of power plant. World wide experience. Speaks German, Portuguese, Scandinavian. Desires position in the Tropics anywhere, South America, East preferred. C-2214.

TEACHER OF PHYSICS AND ENGINEERING, available for second semester. Five years university teaching, and thirteen years' engineering experience specializing on steam and electric problems in industry. Two years university extension teaching while practising. American, 40, M. S. degree, Protestant and married. Interview solicited. B-4451.

APPRAISAL AND ELECTRICAL ENGINEER, 36, married, experienced in power plant, substation and transmission line construction; investigations, special studies, reports, etc. Desires position supervising engineer, inspector or as appraisal engineer. Available at once. Location preferred, New York City, East or South. C-1652.

GRADUATE ENGINEER-DRAFTSMAN, electrical, structural and reinforced concrete (total seven years) experience applied to power plants, bridges and steel mill buildings, desires to make a change to advance and better. Available on short notice. B-8852.

DRAFTSMAN, 24, single, engineering night student, with three years' experience in electrical-mechanical drafting, desires position with responsible firm. Salary $2100. Location, Pittsburgh, preferably near Schenley Park. Available two weeks. C-2356.

ELECTRICAL ENGINEER, technical graduate, thoroughly familiar with calculation, design, construction, operation and maintenance of transmission line, invites correspondence with view toward establishing a connection with responsible firm. Prefers locating in foreign country or Southern States. C-2368.

OPERATING ENGINEER, university graduate in electrical engineering, with four years of experience operating modern type power stations and substations with both automatic and remote control systems, desires job in engineering department of a public utility. Any location. Twenty-nine years old and single. Available in two weeks. C-2380.

MANAGER OR SUPERINTENDENT, 38, married, public utility executive, technical graduate, thirteen years' varied experience in engineering and operation. Especially interested in sales promotion, rates and contact with the public. Desires position in the operating department of a public utility. Location preferred, United States. A-4018.

ENGINEER, with public utility experience, including industrial power sales work. Experience with a large industrial covering steam and power production, maintenance, rehabilitation, etc., also test floor and erecting experience with large electrical manufacturer. Cornell graduate, M. E., E. E. Only prospect of reasonable permanent employment considered. B-6764.

ELECTRICAL ENGINEER, 24, Swiss, recent German university graduate, 1925. Speaks German, English and French. Eight months with big New York power plant company as draftsman. Wishes change, engineering work. Position with chance for advancement, in field or shop preferred. Wants to go anywhere. C-2395.

ELECTRICAL-MECHANICAL ENGINEER, Stanford, Cornell, over twenty-five years business, manufacturing, machinery designing, and general engineering experience, East and West. Recently assistant chief engineer prominent Western manufacturer. Available immediately. Prefers location, Los Angeles or vicinity. C-2390.

ELECTRICAL-MECHANICAL ENGINEER, graduated from the Royal Turin's Polytechnic (Italy), 31, single, four years in United States; inventive ability, several patents, design electrical machines experience. At present designing engineer in radio engineering department of leading company. Willing to travel or go abroad also. Speaks English, French, Italian. Desires to connect with reliable concern. B-7208.

TECHNICAL GRADUATE, 27, married, eight years' experience in maintenance, mechanical, construction and radio operating and sales, desires position, permanently situated, anywhere in Middlewest or West Coast. Available immediately, correspondence invited. C-2402.

TEACHER, ELECTRICAL ENGINEERING, desires to make a change. Over ten years of teaching experience covering all the usual courses. Practical broad experience covering design, construction and application. Desires professorship in a recognized institution. B-7083.

GRADUATE ELECTRICAL ENGINEER, 34, graduated from German College and Polytechnic Institute. Several years' experience in Europe in engineering and drafting work for transmission of power and power plants. Four years' American experience as designer and draftsman. For a time with electric construction of power plant. Employed at present, desires position as draftsman, or with electrical construction company. Available two weeks. Records on request. C-2408.

PATENT ATTORNEY, 25, electrical engineering graduate, member of bar of Supreme Court of District of Columbia and of D. C. Court of Appeals. For last three and one-half years an examiner in U. S. Patent office, mostly electrical cases. Three years of law school, L. L. B. degree in February 1927. Desires position with patent attorney, or electrical manufacturing company, preferably in Middlewest, about March 1st. C-2405.

ELECTRICAL ENGINEER, 31, single, college graduate, four years' experience as designing engineer for switchboards, power plants, substations, two years designing electric machines.

High grade mathematical talent. Wishes position for new developments and calculations of electric machines. Location, East or Middlewest. B-8775.

TECHNICAL GRADUATE IN E. E., 32, married, three years mechanical installations and repairs, five and one-half years general electrical construction, installations, tests, trial runs, reports, etc., power stations and substations (past year and half assistant superintendent in the construction of station), one year operating and maintenance, wishes position. Speaks English, French, some Spanish. Available at once. Location immaterial. Best references. C-2021.

INDUSTRIAL ENGINEER, 34, married, thorough experience in mechanical and electrical plant engineering work. Thirteen years' practical experience in all phases of industrial maintenance, construction work, in a wide variety of industries such as steel, textile, chemical and small parts manufacture. Licensed professional engineer. Location, United States. B-5026.

1925 GRADUATE ELECTRICAL ENGINEER, desires position with public utility. One year's experience in overhead distribution. Available on reasonable notice. C-294.

GRADUATE ELECTRICAL ENGINEER, 28, single, G. E. test, inspection and test of automatic telephone equipment, maintenance engineering problems. Supervision of installation various types electrical machines, design lighting systems, and indoor, outdoor substations. Desires responsible position with firm or public utility in construction of transmission projects or hydro-electric developments. Available now. C-2268.

MEMBERSHIP — Applications, Elections, Transfers, Etc.

ASSOCIATES ELECTED JANUARY 21, 1927

ALLEN, JAMES C., Electrician, 1st Class, Stone & Webster, Inc., Washington, D. C. and Boston, Mass.; for mail, Silver Springs, Md.

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WALTERS, EDWARD, Electrical Maintenance Dept., Cleveland Electric Illuminating Co., Cleveland, Ohio.

WATKIN, HAROLD, Engineer-in-charge, Talbot St. & St. Ann's Power Stations, Electricity Dept., Nottingham Corporation, Nottingham, Eng.

WATTERS, RAY ARMSTRONG, Asst. Physicist, Dr. Hunter B. Spencer X-Ray Laboratory, 8th & Church Sts., Lynchburg, Va.

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WEAVER, PAUL A., Salesman, Electric Storage Battery Co., 308 Coal Exchange Bldg., Wilkes-Barre, Pa.

WEBER, LOUIS, District Inspector of Electricity & Gas, Dept. of Trade & Commerce, Post Office Bldg., Regina, Sask., Can.

WEILENMANN, BERTIL E. A., Draughtsman, Metropolitan Elec. Mfg. Co., Blvd. & 14th St., Long Island City; res., Bronx, New York, N. Y.

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WILSON, ELMER F., Design Draftsman, Engg. Dept., Houston Lighting & Power Co., Houston, Texas.

WINCKLER, GUNNAR, Research Engineer, General Electric Co., Lynn, Mass.

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WRIGHT, MATTHEW V., Chief Engineer & Purchasing Agent, Mutual Tel. Co., 24 E. 10th St., Erie, Pa.

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ZINN, GEORGE WILLIAM, Foreman, Brooklyn Edison Co., 360 Pearl St., Brooklyn, N. Y.

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Total 233.

ASSOCIATES REELECTED JANUARY 21, 1927

DEELWATER, CARL L., Member of Technical Staff, Bell Telephone Laboratories, Inc., 463 West St., New York; res., Port Richmond, S. I., N. Y.

McGRATH, WARREN M., Telephone Equipment Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York, N. Y.

MURPHY, JOSEPH P., Secretary, Dept. of Electricity, 205 City Hall, San Francisco, Calif.

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RUSSELL, WITMER, Commercial Engineer, The New York Edison Co., 393 7th Ave., New York, N. Y.

SWEET, GERRIT LANSING, Equipment Engineer, Bell Telephone Laboratories, Inc., 463 West St., New York; res., Brooklyn, N. Y.

MEMBER REELECTED JANUARY 21, 1927

GOODING, ROBERT F., District Representative, Condit Electric Mfg. Corp., 921 Empire Bldg., Pittsburgh, Pa.

MEMBERS ELECTED JANUARY 21, 1927

GIBBS, CLAYTON T., Electrical Engineer, Holmes & Sanborn, 912 Black Bldg., Los Angeles, Calif.

JOHNSTON, ROBERT MARSH, Consulting Elec. Engineer, Jeffery-Dewitt Insulator Co., Kenova, West Va.

LATHAM, JOHN W. L., Jr., Facilities Engineer, Chesapeake & Potomac Telephone Company, 725 13th St., N. W., Washington, D. C.

POLIVANOFF, MICHAEL C., Consulting Engineer, Prof. of Elec. Engg., Technical High School, Noguin Sq., Glavelectro, Moscow, Russia.

PEELING, CHARLES URIEL, Division Supt., Pennsylvania Power & Light Co., Bethlehem, Pa.

PORTER, EDWARD YOUNGS, Distribution Engineer, The Southern Sierras Power Co., Riverside, Calif.

PULHAM, GEORGE B., Chief Erecting Engineer, Metropolitan-Vickers Electrical Co., Ltd., Hong Kong House, Council St., Calcutta, India.

TAYLOR, HOWARD SMITH, Consulting Engineer, Dayton, Ohio and Montreal, Quebec; for mail, Jefferson Street Arcade, Dayton, Ohio.

TRANSFERRED TO GRADE OF FELLOW JANUARY 21, 1927

DENTON, ALPHEUS P., President & Chief Engineer, Denton Engineering & Construction Co., Kansas City, Mo.

MILLER, KEMPSTER B., Consulting Engineer, Pasadena, Calif.

TRANSFERRED TO GRADE OF MEMBER JANUARY 21, 1927

BARROWS, WILLIAM E., Professor of Electrical Engineering, University of Maine, Orono, Me.

BASTON, CYRIL E., Engineer, Railway Equipment Engineering Dept., Westinghouse Elec. & Mfg. Co., East Pittsburgh, Pa.

BRENTLINGER, C. M., General Inspector, Western Union Telegraph Co., New York, N. Y.

CONNELL, EDWIN L., Chief Engineer, Van Dorn Electric Tool Co., Cleveland, Ohio.

COPELAND, CLEM A., Assistant Electrical Engineer, Bureau of Power & Light, Los Angeles, Calif.

COX, HERBERT H., Supt. Distributing Stations, Bureau of Power & Light, Los Angeles, Calif.

FREEMAN, WILLIAM E., Assistant Dean, College of Engineering, University of Kentucky, Lexington, Ky.

FURST, WALTER A., Manager, Engineering Dept., Westinghouse Elec. & Mfg. Co., Detroit, Mich.

GRIMES, WILLIAM F., Meter and Relay Engineer, Westinghouse Elec. & Mfg. Co., Los Angeles, Calif.

HENNINGER, G. ROSS, Engineering Editor, *Journal of Electricity*, San Francisco, Calif.

HICKERNELL, L. F., Assistant Investigations Engineer, Commonwealth Power Corp. of Michigan, Jackson, Mich.

HITCHCOCK, HARRY W., Transmission & Protection Engineer, Southern California Tel. Co., Los Angeles, Calif.

HOLMES, FREDERICK, Vice-President and Secretary, Duncan Electric Mfg. Co., Lafayette, Ind.

LUNSFORD, JESSE B., Technical Assistant, Design Division, Bureau of Engineering, Navy Department, Washington, D. C.

MOYER, HERBERT C., Chief Engineer, Standards Laboratory, Pennsylvania Power & Light Co., Hazleton, Pa.

NELSON, AARON L., Asst. Engineer, Railway Locomotive Engineering Dept., General Electric Co., Schenectady, N. Y.

PURDY, HENRY T., Consulting & Construction Engineer, San Jose, Costa Rica.

ROSS, JAMES HARVEY, Chief Electrician, Freeport Sulphur Co., Freeport, Tex.

SALBERG, JOHN, Representative, Westinghouse Electric & Mfg. Co., Salt Lake City, Utah.

SHUMAN, JESSE W., Secretary-Treasurer, Power Engineering Co., Minneapolis, Minn.

SIEGMUND, HUMPHREYS O., Member of Technical Staff, Bell Telephone Laboratories, Inc., New York, N. Y.

UNDERHILL, GEORGE H., Distribution Engineer, Central Hudson Gas & Electric Co., Poughkeepsie, N. Y.

WRIGHT, C. R., President & Treasurer, Wright-Cason Electric Co., Knoxville, Tenn.

RECOMMENDED FOR TRANSFER

The Board of Examiners, at its meeting held January 14, 1927, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the National Secretary.

To Grade of Member

BEERY, EARL J., Assistant to General Superintendent of Power, Puget Sound Power & Light Company, Seattle, Wash.

NOTTORF, WILLIAM E. A., Assistant to Executive Vice-President, Automatic Electric Inc., Chicago, Ill.

WELKE, RUDOLPH A., Professional Electrical Engineer, Adlanco Industrial Products Corp., New York, N. Y.

APPLICATIONS FOR ELECTION

Applications have been received by the Secretary from the following candidates for election to membership in the Institute. Unless otherwise indicated, the applicant has applied for admission as an Associate. If the applicant has applied for direct admission to a higher grade than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the Secretary before February 28, 1927.

Achenbach, C. H., Bell Telephone Laboratories, Inc., New York, N. Y.

Allan, J. C., Canadian General Electric Co., Toronto, Ont., Can.

Alrich, E. W., General Electric Co., Schenectady, N. Y.

Andreae, S. C., Wisconsin Electric Mfg. Co., Milwaukee, Wis.

Arguimbau, F., Representative, "Compania Hispano Americano de Electricidad" of Barcelona, Spain; for mail, New York, N. Y.

Atkins, J. G., U. S. Navy, Bethlehem Shipbuilding Corp., Quincy, Mass.

Babbitt, F. M., West Penn Power Co., Uniontown, Pa.

Barbera, A. A., Electrical & Sales Engineer, Los Angeles, Calif.

Barrett, E. C., The Chesapeake & Telephone Co., Washington, D. C.

Baxter, W. J. F., Hydro-Electric Power Commission, Toronto, Ont., Can.

Bellman, W. E., (Member), The Western Union Telegraph Co., New York, N. Y.

Bendernagel, W. H., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.

Bescoby, F. E., British Columbia Electric Railway Co., Vancouver, B. C., Can.

Bewley, L. V., General Electric Co., Pittsfield, Mass.

Borgeson, C. A., American Tel. & Tel. Co., Chicago, Ill.

Boruszak, N., F. A. Vaughn, Inc., Milwaukee, Wis.

Bradley, H. E., Potomac Electric Power Co., Washington, D. C.

Brennan, W. W., Edison Electric Illuminating Co. of Brockton, Brockton, Mass.

Brickson, Herbert O., Wisconsin Dept. of Markets, Stevens Point, Wis.

Brown, E. E., Philadelphia Electric Co., Philadelphia, Pa.

Brown, F. H., Denver Tramway Corp., Denver, Colo.

Buckley, C. L., Instructor, High School, Trenton, N. J.

Callender, F. K., (Member), The Okonite-Callender Cable Co., Paterson, N. J.

Carlin, F. M., Western Electric Co., Inc., Philadelphia, Pa.

Case, N. G., The Syracuse Lighting Co., Inc., Syracuse, N. Y.

Charlton, H. C., A. Reyrolle & Co., Ltd., Toronto 2, Ont., Can.

Clement, A. E., Natrona Light & Power Co., Natrona, Pa.

Clendening, C. A., (Member), Manitoba Power Commission, Winnipeg, Manitoba

Cochran, W. H., General Electric Co., Erie, Pa.

Codd, W. A., Rensselaer Polytechnic Institute, Troy, N. Y.

Conrad, A. G., Ohio State University, Columbus, Ohio

Cook, V. M., United Electric & Power Co., New York, N. Y.

Costello, J. M., Niagara Power Co., Syracuse, N. Y.

Cramer, C. H., Western Union Telegraph Co., New York, N. Y.

Crom, G. C., Jr., American Transformer Co., Newark, N. J.

Crosby, P. W., Philadelphia Electric Co., Philadelphia, Pa.

Crosby, R. H., University of Washington, Seattle, Wash.

Cummings, C. S., Western Union Telegraph Co., New York, N. Y.

Daniels, J. S., The Pacific Tel. & Tel. Co., San Francisco, Calif.

Di Lucci, A., Victor X-Ray Corp., Chicago, Ill.

Dixon, W. R., (Member), Florida Public Service Co., Orlando, Fla.

Dow, I. M., The Chesapeake & Potomac Telephone Co., Washington, D. C.

Eaton, J. R., Consumers Power Co., Jackson, Mich.

Evans, G. T., Public Service Electric & Gas Co., of N. J., Irvington, N. J.

Faesi, H. A., American Brown Boveri Electric Corp., Camden, N. J.

Fay, O. J., Western Electric Co., Inc., Chicago, Ill.

Fletcher, W. T., The Western Union Telegraph Co., New York, N. Y.

Formoso, J. F., Mexican Light & Power Co., Mexico, D. F., Mex.

Foye, J. F., Blue Diamond Materials Co., Malden, Mass.

Fung, J. H., Pratt Institute, Brooklyn, N. Y.

Gaertner, A. H., Commonwealth Edison Co., Chicago, Ill.

Gluckman, M., Electrical Testing Laboratories, Inc., New York, N. Y.

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Greiner, A. M., Brandes Products Corp., Newark, N. J.

Griffin, B. F., Staff Electric Co., Milwaukee, Wis.

Grothe, A. F., Ohio Bell Telephone Co., Cleveland, Ohio

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Grunenthal, C. J., New York Edison Co., New York, N. Y.

Haley, W., Public Service Electric & Gas Co., Newark, N. J.

Hall, O. C., American Tel. & Tel. Co., New York, N. Y.

Hammerle, F. L. J., The Syracuse Lighting Co., Inc., Syracuse, N. Y.

Hanford, R. E., Western Union Telegraph Co., New York, N. Y.

Harper, Edward E., Madison Coal Corp., Glen Carbon, Ill.
Heller, P. E., New York Edison Co., New York, N. Y.
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Hodges, R. C., Public Service Production Co., Newark, N. J.
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Johnson, H. L., Western Electric Co., Kearny, N. J.
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Keady, T. P., N. Y. & Queens Elec. Lt. & Pr. Co., Flushing, N. Y.
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Kenrick, R. S., Railway Elec. Engineer, Railway Signaling, Chicago, Ill.
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Kyvig, S. O., Commonwealth Edison Co., Chicago, Ill.
Lambert, L. S., Northwestern Bell Tel. Co., Omaha, Nebr.
Larsson, E., The Koppers Co., Pittsburgh, Pa.
Laubscher, W. F., Monongahela West Penn Public Service Co., Fairmont, West Va.
Leach, H. J., Jr., Brown & Caine, Chicago, Ill.
Leland, C. A. Jr., (Member), Kansas Power & Light Co., Topeka, Kans.
Levin, S. A., Engg., Dept., N. E. L. A., New York, N. Y.
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Olsen, B., General Electric Co., Spokane, Wash.
Orr, J. J., Oakland Motor Car Co., Pontiac, Mich.
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Pittman, D., Wagner Electric Corp., St. Louis, Mo.
Platto, L. F., The Syracuse Lighting Co., Syracuse, N. Y.
Pliego, A., Jr., Mexican Light & Power Co., Mexico, D. F., Mex.
Poling, C. V., Commonwealth Power Corp., Jackson, Mich.
Pope, H. T., Niagara, Lockport & Ontario Power Co., Syracuse, N. Y.
Powers, T. N., Postal Telegraph-Cable Co., New York, N. Y.
Pray, R. P., (Member), Goodwin-Pray, Inc., Newark, N. J.
Price, G. F., Southeastern Underwriters Association, Atlanta, Ga.
Rearden, R. C., Columbus Railway, Power & Light Co., Columbus, Ohio
Reinhard, A. J., Western Union Telegraph Co., New York, N. Y.
Rhinehart, R. J., Arkansas Power & Light Co., Pine Bluff, Ark.
Richardson, C. P., (Member,) Canadian General Electric Co., Ltd. Toronto, Ont., Can.
Roehrig, G. J., The Syracuse Lighting Co., Inc., Syracuse, N. Y.
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Shimp, C. S., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
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Smith, A. V., The New York Edison Co., New York, N. Y.
Smith, C. C., Canadian National Railways, Peterboro, Ont., Can.
Smith, J. B., Dixie Construction Co., Birmingham, Ala.
Smith, J. E., Rockland Light & Power Co., Nyack, N. Y.
Spears, M. G., The New York Edison Co., New York, N. Y.
Springer, C. B., General Electric Co., Schenectady, N. Y.
Stearn, F. A., (Member), Bell Telephone Laboratories, Inc., New York, N. Y.
Steigleder, F. N., Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Stewart, R. J., West Penn Power Co., Connellsville, Pa.
Storminger, G., Public Service Production Co., Newark, N. J.
Strohmer, G. A., The Detroit Edison Co., Detroit, Mich.
Sullivan, E. L., Public Service Production Co. of N. J., Newark, N. J.
Swanson, E. J., Bureau of Power & Light, Los Angeles, Calif.
Svoboda, C., Western Electric Co., Chicago, Ill.
Tellez, J. S., Detroit Edison Co., Detroit, Mich.
Tellkamp, B. F., Cleveland Vacuum Tube Works, Nela Park, East Cleveland, Ohio
Theuner, A. E. K., Bell Telephone Laboratories, Inc., New York, N. Y.
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San Francisco	D. I. Cone	A. G. Jones, 807 Rialto Bldg., San Francisco, Calif.
Saskatchewan	S. R. Parker	W. P. Brattle, Dept of Telephones, Telephone Bldg., Regina, Sask.
Schenectady	R. E. Doherty	R. F. Franklin, Room 301, Bldg. No. 41, General Electric Co., Schenectady. N. Y.
Seattle	C. E. Mong	C. R. Wallis, 609 Colman Bldg., P. O. Box 1858, Seattle, Wash.
Sharon	H. L. Cole	L. H. Hill, Westinghouse Elec. & Mfg. Co., Sharon, Pa.
Southern Virginia	W. S. Rodman	J. H. Berry, 1338 Rockbridge Ave., Norfolk, Va.
Spokane	Richard McKay	James B. Fisken, Washington Water Power Co., Lincoln & Trent, Spokane, Wash.
Springfield, Mass.	L. F. Curtis	J. Frank Murray, United Electric Light Co., 251 Wilbraham Ave., Springfield, Mass.
Syracuse	C. E. Dorr	F. E. Verdin, 615 City Bank Bldg., Syracuse, N. Y.
Toledo	O. F. Rabbe	Max Neuber, 1257 Fernwood Ave., Toledo, Ohio
Toronto	M. B. Hastings	F. F. Ambuhl, Toronto Hydro-Electric System, 226 Yonge St., Toronto, Ontario
Urbana	J. T. Tykociner	L. B. Archer, 301 Electrical Engineering Lab., University of Illinois, Urbana, Ill.
Utah	B. C. J. Wheatlake	D. L. Brundige, Utah Power & Light Co., Box 1790, Salt Lake City, Utah
Vancouver	R. L. Hall	C. W. Colvin, . . Electric Railway Co., 425 Carrall St., Vancouver, B. C.
Washington, D. C.	C. A. Robinson	D. S. Wegg, Dept. of Commerce, Room 817, Pennsylvania Ave., at 19th St., N. W., Washington, D. C.
Worcester	C. F. Hood	F. B. Crosby, Morgan Construction Co., 15 Belmont St., Worcester, Mass.
Total 52		

LIST OF BRANCHES

Name and Location	Chairman	Secretary	Counselor (Member of Faculty)
Akron, Municipal University of, Akron, Ohio	Lee J. Shaffer	S. K. Worthen	J. T. Walther
Alabama Polytechnic Institute, Auburn, Ala	J. D. Stewart	T. S. Lynch	W. W. Hill
Alabama, University of, University, Ala	Sewell St. John	J. M. Cardwell, Jr.	
Arizona, University of, Tucson, Ariz	J. W. Cruse	Audley Sharpe	J. C. Clark
Arkansas, University of, Fayetteville, Ark	Carroll Walsh	W. H. Mann	W. B. Stelzner
Armour Institute of Technology, Chicago, Ill	M. T. Goetz	C. W. Schramm	D. P. Moreton
Brooklyn Polytechnic Institute, Brooklyn, N. Y	William Berger	Joseph Heller	Robin Beach
Bucknell University, Lewisburg, Pa	A. Fogelsanger	J. D. Johnson	W. K. Rhodes
California Institute of Technology, Pasadena, Calif	Thomas L. Gottier	Alan E. Capon	R. W. Sorensen
California, University of, Berkeley, Calif	F. H. McCune	A. G. Montin	T. C. McFarland
Carnegie Institute of Technology, Pittsburgh, Pa	J. R. Power	R. O. Perrine	B. C. Dennison
Case School of Applied Science, Cleveland, O	C. J. Brumbaugh	E. E. Samson	H. B. Dates
Catholic University of America, Washington, D. C	W. S. Sparks	C. S. Daily, Jr.	T. J. MacKavanaugh
Cincinnati, University of, Cincinnati, O	C. W. Taylor	W. C. Osterbrock	W. C. Osterbrock
Clarkson College of Technology, Potsdam, N. Y	H. J. Myrback	W. E. Turnbull	A. R. Powers
Clemson Agricultural College, Clemson College, S. C	L. R. Miller	J. U. Wilson	S. R. Rhodes
Colorado State Agricultural College, Ft. Collins, Colo	C. O. Nelson	D. W. Asay	
Colorado, University of, Boulder, Colo	A. D. Thomas	J. A. Setter	W. C. DuVall
Cooper Union, New York, N. Y	H. T. Wilhelm	E. T. Reynolds	Norman L. Towle
Denver, University of, Denver, Colo	Harold Henson	Allea Ohlson	R. E. Nyswander
Drexel Institute, Philadelphia, Pa	H. D. Baker	R. S. Eininger, Jr.	E. O. Lange
Florida, University of, Gainesville, Fla	W. Stanwix-Hay	R.D. Ross	J. M. Weil
Georgia School of Technology, Atlanta, Ga	W. M. McGraw	F. L. Kaestle	E. S. Hannaford
Idaho, University of, Moscow, Idaho	J. W. Gartin	S. Blore	J. H. Johnson
Iowa State College, Ames, Iowa	A. G. Baumgartner	J. B. Cecil	F. A. Fish
Iowa, University of, Iowa City, Iowa	Theo. VanLaw	E. J. Hartman	A. H. Ford
Kansas State College, Manhattan, Kans	A. M. Young	John Yost	C. E. Reid
Kansas, University of, Lawrence, Kans	Elmer Bayles	Miss. Lottye Young	G. C. Shaad
Kentucky, University of, Lexington, Ky	J. A. Weingartner	C. E. Albert	
Lafayette College, Easton, Pa	Herbert Heinrich	Daniel Paul	Morland King
Lehigh University, S. Bethlehem, Pa	A. W. Staller	J. Lloyd Dancy	J. L. Beaver
Lewis Institute, Chicago, Ill	James S. Howe	O. D. Westerberg	F. A. Rogers
Louisiana State University, Baton Rouge, La	K. J. Ozment	E. P. Athens	M. B. Voorhies
Maine, University of, Orono, Me	P. E. Watson	R. F. Scott	W. E. Barrows, Jr.
Marquette University, Milwaukee, Wis	R. M. Franey	E. T. Baldwin	J. F. H. Douglas
Massachusetts Institute of Technology, Cambridge, Mass	Constantine Bary	E. A. Michelman	W. H. Timbie
Michigan State College, East Lansing	W. H. Bartels	J. C. Phelps	L. S. Foltz
Michigan, University of, Ann Arbor, Mich	M. H. Nelson	H. R. Stevenson	B. F. Bailey
Milwaukee, Engineering School of, Milwaukee, Wis	L. H. La Fever	W. H. Freisleben	John D. Ball
Minnesota, University of, Minneapolis, Minn	C. H. Burmeister	J. H. DuBois	H. Kuhlmann
Mississippi Agricultural & Mechanical College, A. & M. College, Miss	H. M. Alford	B. W. Robins	
Missouri, University of, Columbia, Mo	V. L. Tiller	J. L. Egbert	M. P. Weinbach
Missouri School of Mines and Metallurgy, Rolla, Mo	W. J. Maulder	R. P. Baumgartner	I. H. Lovett
Montana State College, Bozeman, Mont	W. E. Pakala	J. A. Thaler	J. A. Thaler
Nebraska, University of, Lincoln, Neb	M. E. La Bounty	R. D. Reed	F. W. Norris
Nevada, University of, Reno, Nev	George Fairbrother	Cornelius Fort	S. G. Palmer
Newark College of Engineering, Newark, N. J	H. G. Patton	C. H. Clarendon, Jr.	J. C. Peet
New Hampshire, University of, Durham, N. H	T. C. Tappan	F. W. Hussey	L. W. Hitchcock
New York, College of the City of, New York, N. Y	Harold Wolf	A. H. Rapport	Harry Baum
New York University, New York, N. Y	H. U. Hefty	Henry Och	J. Loring Arnold
North Carolina State College, Raleigh, N. C	J. W. Fagan	W. E. Mathews	G. C. Cox
North Carolina, University of, Chapel Hill	H. L. Coe	C. M. Lear	P. H. Daggett
North Dakota, University of, University	Authur Eielson	W. W. Kloster	D. R. Jenkins
Northeastern University, Boston, Mass	W. P. Raffone	John L. Clark	W. L. Smith
Notre Dame, University of, Notre Dame, Ind	W.C. Davis	C. H. Schamel	J. A. Caparo
Ohio Northern University, Ada, Ohio	M. Heft	P. W. Wadsworth	I. S. Campbell
Ohio State University, Columbus, O	Lee P. Doyle	Joseph Seaman	F. C. Caldwell
Ohio University, Athens, Ohio	Clarence Kelch	Glen R. Smith	A. A. Atkinson
Oklahoma A. & M. College, Stillwater, Okla	H. M. Horton	Lee Rogers	Edwin Kurtz
Oklahoma, University of, Norman, Okla	G. B. Brady	H. C. Mitschrich	F. G. Tappan
Oregon Agricultural College, Corvallis, Ore	F. D. Crowther	E. F. Reddy	F. O. McMillan
Pennsylvania State College, State College, Pa	F. F. Wilkins	C. C. Huggler	L. A. Doggett
Pennsylvania, University of, Philadelphia	F. H. Riordan, Jr.	W. H. Hamilton	C. D. Fawcett
Pittsburgh, University of, Pittsburgh, Pa	M. G Jarrett	D. P. Mitchell	H. E. Dyche
Princeton University, Princeton, N. J	John Reine	J. M. Myers	Malcolm MacLaren
Purdue University, Lafayette, Ind	A. Howard	T. B. Holliday	A. N. Topping
Rensselaer Polytechnic Institute, Troy, N. Y	F. M. Sebast	W. C. Michels	F. M. Sebast
Rhode Island State College, Kingston, R. I	G. A. Eddy	C. Easterbrooks	Wm. Anderson
Rose Polytechnic Institute, Terre Haute, Ind	D. L. Fenner	W.F. A. Hammerling	C. C. Knipmeyer
Rutgers University, New Brunswick, N. J	E. C. Siddons	W. H. Bohlke	F. F. Thompson
Santa Clara, University of, Santa Clara, Calif	Lloyd Whitwam	W. P. Fisher	D. W. Griswold
South Dakota State School of Mines, Rapid City, S. D	C. Allen	Harold Eade	J. O. Kammerman
South Dakota, University of, Vermillion, S. D	Maurice H. Nelles	Stanley Boegler	B. B. Brackett
Southern California, University of, Los Angeles, Calif	Karl Raife	E. E. Smith	C. E. Guse
Stanford University, Stanford University, Calif	A. V. Pering	J. G. Sharp	T. H. Morgan
Stevens Institute of Technology, Hoboken, N. J	D. B. Wesstrom	G. E. Witham	Frank C. Stockwell
Swarthmore College, Swarthmore, Pa	Edw. Fairbanks	Walter Denkhaus	Lewis Fussell
Syracuse University, Syracuse, N. Y	G. F. Kern	T. P. Hall	C. W. Henderson
Tennessee, University of, Knoxville, Tenn	F. N. Green	B. M. Gallaher	Charles A. Perkins
Texas A. & M. College, College Station, Texas	C. A. Altenbern	T. L. Pratt	F. C. Bolton
Texas, University of, Austin, Tex	F. W. Langner	H. W. Zuch	J. A. Correll
Utah, University of, Salt Lake City, Utah	J. I. Farrell,	M. L. Hoag,	J. F. Merrill
Virginia Military Institute, Lexington, Va	R. P. Williamson	M. L. Waring	S. W. Anderson
Virginia Polytechnic Institute, Blacksburg, Va	R. M. Hutcheson	M. B. Cogbill	Claudius Lee
Virginia, University of, University, Va	R. C. Small	H. M. Roth	W. S. Rodman
Washington, State College of, Pullman, Wash	S. H. White	H. R. Meahl	H. V. Carpenter
Washington University, St. Louis, Mo	E. B. Kempster, Jr.	R. L. Belshe	H. G. Hake
Washington, University of, Seattle, Wash	C. M. Murray, Jr.	Roy H. Crosby	George S. Smith
Washington and Lee University, Lexington, Va	C. M. Wood	R. E. Kepler	R. W. Dickey
West Virginia University, Morgantown, W. Va	I. L. Smith	P. E. Davis	A. H. Forman
Wisconsin, University of, Madison, Wis	Benj. Teare	N. B. Thayer	C. M. Jansky
Worcester Polytechnic Institute, Worcester, Mass	D. A. Calder	C. H. Kauke	H. A. Maxfield
Wyoming, University of, Laramie, Wyo	John Hicks	Edward Joslin	G. H. Sechrist
Yale University, New Haven, Conn	W. W. Parker	J. W. Hinkley	Charles F. Scott

Total 94

DIGEST OF CURRENT INDUSTRIAL NEWS

NEW CATALOGUES AND OTHER PUBLICATIONS

Mailed to interested readers by issuing companies

Turbo-Generators.—Bulletin 100, 48 pp. Describes American Brown Boveri steam turbo-generators for all purposes. American Brown Boveri Electric Corporation, 165 Broadway, New York.

Paper Machine Drive.—Bulletin GEA 527, 20 pages. Describes sectional drive (regulator type) for paper machines. General Electric Company, Schenectady, N. Y.

Ball Bearings.—Bulletin P-1, 20 pp. Describes Gurney ball bearings in deep well pumps and includes typical mountings and calculation tables. Marlin-Rockwell Corporation, Gurney Ball Bearing Division, Jamestown, N. Y.

Wiring Devices.—1927 catalog, completely revised, and fully illustrated, describes over 4000 wiring devices manufactured by the Bryant Electric Company, Bridgeport, Conn.

Automatic Compensators.—Bulletin 1042-F. Describes EC&M automatic compensators for 110 to 550 volts a-c. squirrel-cage and synchronous motors. Electric Controller & Mfg. Company, 2700 East 79th Street, Cleveland, Ohio.

Motors.—Bulletin, 12 pp. "Brass Tacks About Selecting Motors." Discusses the policy of permitting appliance and machine purchasers to specify motor drives. The Master Electric Company, Linden & Master Avenues, Dayton, Ohio.

Porcelain Mountings.—Bulletin 316. Describes Kearney special porcelain mountings for Kearney expulsion plug cut-outs. The use of a Kearney fuse puller is also described. James R. Kearney Corporation, 4224 Clayton Ave., St. Louis, Mo.

Electric Furnaces.—Folder. Describes steel melting with Ajax-Northrup high frequency furnaces. These furnaces are used in the preparation of alloys for telephone apparatus, radio transformers, electrical resistance alloys, magnetic steels, etc. Ajax Electrothermic Corporation, Trenton, N. J.

Limit Stops.—Bulletin 1037-C. Describes type "B" limit stops for use with direct and alternating current motors. Their principal application is on electric cranes and other motor driven machines which must be automatically stopped when reaching a given position. The Electric Controller & Mfg. Company, 2700 East 79th Street, Cleveland, Ohio.

Switching Equipment.—Bulletin 312, 12 pp., describes Kearney new outdoor type fuse switches, disconnecting switches, choke coils, and combinations, 7500 and 15000 volts, equipped with wood or malleable iron bases. Illustrations and descriptions with prices and quantity discounts are also listed. This new switching equipment is interchangeable and convertible, permitting three mountings from the same switch or choke coil without adding a single part. The insulators, fuse cartridges and disconnect blades are also interchangeable. James R. Kearney Corporation, 4224 Clayton Avenue, St. Louis, Mo.

NOTES OF THE INDUSTRY

N. E. M. A. to Move Headquarters.—The National Electric Manufacturers Association will move from its present quarters at 30 East Forty-Second Street, New York City, to the new Graybar Building, just East of the Grand Central Terminal, about the time that building is completed, probably April first.

Westinghouse Subsidiaries Become Branch Works.—The corporate form of two subsidiaries of the Westinghouse Electric & Manufacturing Company has been discontinued and merged into the parent company as branch works. The companies so affected are the Westinghouse Electric Products Company, Mansfield, Ohio, to be known as the Mansfield Works, and the George Cutter Company, of South Bend, Indiana, to be designated in the future as the Street Lighting Department.

W. N. Matthews Corporation Appoints New Representative.—Announcement has been made that Arthur E. Bacon, 1429 Eighteenth Street, Denver, Colo., will represent the W. N. Matthews Corporation, St. Louis, in Colorado, New Mexico, Wyoming and a number of counties in the state of Nebraska. Mr. Bacon, who succeeds the O. H. Davidson Equipment Company of Denver, was formerly manager of the Electrical Department of the Mine & Smelter Supply Company.

Recent Westinghouse Orders.—A second contract has been placed with the Westinghouse Company for a 48,500 kv-a. turbine generator to be installed at the Colfax Station of the Duquesne Light Company in Cheswick by the Byllesby Engineering and Management Corporation. Orders for four 33,333 kv-a. transformers and seven 25,000 kv-a. transformers have been received from the Southern California Edison Company. These units will be manufactured at the Sharon Works.

Largest Steel Mill Turbine.—The largest turbine generator ever used by a steel mill will be installed by the Illinois Steel Company at its Gary, Indiana, plant, according to the General Electric Company, manufacturers of the equipment, which will produce 30,000 kw. at 25 cycles, 6600 volts. The tendency of steel mills to use prime movers is indicated by this and also other similar installations to be made by other plants. The Tennessee Coal, Iron & Railroad Company is soon to install two 20,000-kw. turbine generators, and another unit of the same size will be installed by the Bethlehem Steel Company at Sparrow's Point, Md.

New Westinghouse Trickle Charger to be Exhibited.—The Westinghouse Electric & Manufacturing Company will exhibit for the first time their new Rectox trickle charger at the coming Automobile Show in Chicago, the week beginning January 31. The rectifying element of the new charger consists of stacks of alternate discs, or washers, of copper, with one side oxidized, and lead, which elements freely pass current in one direction only, forming a rectifying device. The copper washers, or discs, are oxidized on one side in furnaces under a very high temperature and when separated from each other by a soft metal give the desired results.

General Electric Orders for 1926.—Orders received by the General Electric Company for the year ending December 31, 1926, totaled $327,400,207, an increase of eight per cent, or nearly $25,000,000 over 1925, President Gerard Swope has announced. This is the biggest volume of orders in the company's history, the previous high mark, achieved in 1920, being $318,470,000, or about ten millions below the new record. For the fourth quarter of 1926, orders booked amounted to $80,406,570, compared with $78,636,669 for the last quarter in 1925, a gain of two per cent.

The Western Electric Company has announed the organization of the Electrical Research Products, Inc., of Wilmington, Del., a subsidiary corporation formed to take over that portion of Western Electric business which is not related to the manufacture and distribution of telephone apparatus and supplies for the Bell System. All of the new corporation's stock is owned by the Western Electric Company.

The field of the Electrical Research Products, Inc., will include the commercial development of electrical devices and inventions controlled by the parent company and not suitable for distribution through the Graybar Electric Company, its subsidiary operating in the distribution of electrical supplies.

J. E. Otterson, general commercial manager of Western Electric, becomes general manager of Electrical Research Products, Inc. His office will be at 195 Broadway, New York.